THE
ELEMEMTS
OF
NAVAL ARCHITECTURE:
OR, A
PRACTICAL TREATISE
ON
SHIP-BUILDING.

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CAREFULLY ABRIDGED

By MUNGO MURRAY.

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A

PRACTICAL TREATISE

ON

SHIP-BUILDING.

CHAP. I.

General Proportions for Building.

NAVAL Architecture may be divided into three principal parts.
 I. To give the ship such a figure, or exterior form, as may suit the service she is designed for.
 II. To find the true form of all the pieces of timber that shall be necessary to compose such a solid.
 III. To make proper accommodations for guns, ammunition, provisions, and apartments for all the officers, and likewise for the cargo.

We shall at present only treat of the first of these, namely the exterior figure, and consider it first, as it regards the bottom, that is, the part which lies under water, and may be called the quick-work; or, secondly, the part which is above water, and may be called the dead-work.

In order to give a proper figure to the bottom, all the qualities which are necessary to make a ship answer the service for which she is designed, should be considered. A ship of war should carry her lower tier of guns four or five feet out of the water. A ship for the merchants service should stow the cargo well, and both of them should be made to go well, carry a good sail, steer well, and lie to easily in the sea.

<div align="center">B</div>

<div align="right">Some</div>

Some eminent geometricians have endeavoured to find the form of a folid which may beft anfwer all thefe qualities, and meet with the leaft refiftance in dividing the fluid through which it is to pafs; but have not been able to reduce their theory to practice, by reafon of the different pofitions a fhip is obliged to be in when under fail. The fhip-builders, defpairing to eftablifh this point by mathematical rules, have applied themfelves wholly to their own obfervations and experience, which may indeed fupply the deficiencies of art; but though they may thereby difcover that a fhip has feveral bad qualities, it will not be eafy to determine where the fault lies; for it may be owing to the rigging; and though the fault be not there, yet they cannot be certain in what particular part of the body it is. If their obfervations be affifted by principles drawn from theory, it will conduce very much to attain their end.

As there have been feveral fhips built which have feemed to anfwer all the fervices for which they have been defigned, fome builders have made it their principal ftudy to copy fhips which have gained the applaufe of the feamen. This method they very improperly call the principal rule which fhould be obferved in building. Now, as the bodies of fhips are very different from one another, fo there are, by this means, as many different methods ufed; fome chufing one, and fome another for a ftandard. But it muft be obferved, that even though it were poffible to find fuch a body as fhould give entire fatisfaction, and have all the good qualities that fhould be neceffary to anfwer the fervices propofed, yet this could by no means be eftablifhed as a ftandard by which other fhips of different dimenfions may be built. For admitting we have a firft rate of 100 guns, which by experience has been found to be a very good fhip in all refpects, yet we fhould find ourfelves very much deceived, if we fhould build a fhip of 20 guns by making all the parts have the fame proportion to one another, that they have in that of 100 guns.

The firft thing to be done, in order to lay down the draught of a fhip, is to determine the length, which fhould be either on the lower gun deck, or at the load-water line; for there muft be great care taken that there is a fufficient fpace betwixt the ports. This will oblige us firft to fix the number and dimenfions of the ports, the diftance of the aftermoft port from the tranfom, and of the foremoft from the ftem, and the diftance betwixt the ports. This article may be determined by the following tables:

A Table

A Table of the Number of Ports on each Side of a Ship, according to the Number of Guns, and the Weight of the Shot.

A Ship of 112 Guns.

Decks	Ports	Shot
1	15	48 or 36
2	16	24
3	15	12
Quarter	5	8
Forecastle	3	8
Poop	2	4

A Ship of 102 Guns.

Decks	Ports	Shot
1	14	36
2	15	18
3	14	12
Quarter Forecastle Poop	13	6

A Ship of 74 Guns.

Decks	Ports	Shot
1	13, 14	36
2	14, 15	18
Quarter Forecastle	8, 8	8
Poop		4

A Ship of 64 Guns.

Decks	Ports	Shot
1	12, 13	24
2	13, 14	12
Quarter Forecastle	7, 5	6

A Ship of 58 Guns.

Decks	Ports	Shot
1	12	18
2	13	12
Quarter Forecastle	4	4

The Tiger.

Decks	Ports	Shot
1	11	18
2	12	8
Quarter	3	6
Forecastle	2	4

A Ship of 50 Guns.

Decks	Ports	Shot
1	11	18
2	12	12
Quarter	2	4

A Frigate of 46 Guns.

Decks	Ports	Shot
1	11	12
2	12	8

A Frigate of 32 Guns.

Decks	Ports	Shot
1	10	6
Quarter Forecastle	6	4

A Frigate of 32 Guns.

Decks	Ports	Shot
1	4	8
2	10	6
Quarter Forecastle	2	4

A Frigate of 32 Guns.

Decks	Ports	Shot
1	10	8
2	6	6

A Frigate of 28 Guns.

Decks	Ports	Shot
1	3	8
2	10	4
Quarter	1	4

A Frigate of 24 Guns.

Decks	Ports	Shot
1	10	6
Quarter	2	4

A Frigate of 22 Guns.

Decks	Ports	Shot
1	9	6
Quarter	2	4

Frigates of 20 Guns have 10 Ports on each side on one Deck. Shot 6 lb.

Vessels of 16 guns have 8 ports on one deck, the guns to carry 4 lb. shot.
Vessels of 12 guns have 6 ports on one deck, the guns to carry 4 lb. shot.

A Table

A Table of the Dimensions of the Ports, and Height of their Sells, according to the Weight of the Shot.

Shot	Hei. and brea. of ports					Height of the ports			Sells	
lb.	f. in. l.	f.	in.	f.	in.	1ft Deck	2d Leck	3d Deck	Quarter-Deck and Forecastle	
48	2 9	3	0 or	3	2	f. in.	f. in.			
36	2 8	3	0 or	3	1	2 2				
24	2 5	2	8 or	2	10	2 1	2 0			
18	2 4	2	7 or	2	8	1 11	1 9			
12	2 2 2	2	4 or	2	6	1 10	1 8	1 7		
8	1 9	1	11 or	2	3	1 8	1 6		1 5	
6	1 6	1	8 or	1	11	1 7	1 6		1 5	
4	1 4	1	6 or	1	9	1 5			1 3	

A Table of the Number, Dimensions and Distances betwixt the Ports on the lower Deck; also the Distance betwixt the foremost Port and the Stem, betwixt the Aftmost and the Sternpost.

Ships Names.	N° of Ports	Breadth of Ports	Dift. betw. Ports	Foremost from Stem	Aftmost from Poft	Length on L. Deck	
Amiable	13	2 8	7 6	13 4	9 0	147	
Invincible	13	2 8	7 4	12 4	9 0	144	
Achilles	12	2 8	7 8	18 2	10 6	145	
Toulouſe	12	2 8	7 6	17 4	9 2	141	
Ardent, 64 guns	12	2 8	7 6	17 0	9 2	140 8	
Fleuron, 64 guns	12	2 8	7 8	18 10	10 6	145 8	
Dauphin Royal, 74 guns	13	2 10	7 7	18 2	10 0	156	

Note, An inch *French* meaſure is equal to 1 $\frac{1}{10}$ inch *Engliſh*, and is divided into twelve parts called lines, which are divided into twelve parts, called points.

The next thing to be done is to eſtabliſh the breadth by the midſhip beam; the builders are pretty much divided in proportioning this to the length. Moſt of them conform to dimenſions taken from ſhips of the ſame burthen, and deſigned for the ſame ſervice.

After theſe two dimenſions are determined, the depth of the hold muſt be fixed, which in moſt ſhips is half the breadth; but the form of the body ſhould be conſidered; for a flat floor will require leſs hold than a ſharp one. The diſtances likewiſe between the decks muſt be determined. The following table may be very uſeful towards aſcertaining the three aforeſaid dimenſions.

A Table

A Table of the Length, Breadth, and Depth in Hold of the following Ships.

Ship's Names	Guns	Length at load-water line		Breadth		Depth in the Hold	
		feet	in.	f.	in.	f.	in.
Monareue	74	165		43		20	6
Intrepide	74	165		43		20	6
Alcide	64	149		40	6	19	4
Renommée	30	120		31	8	15	7
Palme	12	85		22	6	10	5
Soleil Royal	80	182		48		23	
Formidable	80	178		44	10	21	10
Tonnant	80	168		46		23	
Sceptre	74	165		43		20	6
Superbe	74	153	6	42	8	21	
Esperance	74	154		42		21	
Magnifique	74	165		43		20	6
Northumberland	68	149		40		20	
Lis	64	149		40		19	
Hercule	64	149		40	6	19	4
Protee	64	150		40	6	19	4
Illuftree	64	150		40	8	20	
Opinatre	64	150		40	4	19	5
Dragon	64	149		40		19	
Leopard	64	146		39	6	18	6
St. Laurent	60	145		39	4	18	8
Amphion	50	145		39		18	7
Amazon	44	148					
Brillant	50	135		35			
Arc-en-Ciel	50	135		37		17	9
Tigre	52	131		37		17	
Alcion	50	132		35	4	18	
Aquilon	46	127		34		17	
Junon	46	138		36	6	16	6
Favorite	36	127		33	6	14	
Anglefea	32	121	8	33	6	16	
Serenne	30	118	0	31	8	15	9
Emeraude	28	118	0	31	8	16	
Galatée	24	110		29		14	6
Mutine	24	110		29		14	6
Cumberland	24	102		26		13	
Marfhal Saxe	22	100		27		14	
Anemone	12	84		22		9	

Ship's Names	Guns	Length	Breadth		Depth	
		feet	f.	in.	f.	in.
Amarante	12	84	22		9	
Elizabeth	64	143	38	4	18	
Brave	80	172	44		21	
Floriffant	74	165	45		22	6
Couronne	74	167	44		22	7
Hardi	64	149	40	6	20	9
Aigle	50	144	39		19	6
Hermione	26	126	33	8	13	8
Juste	70	151	42		21	
Triponne	26	114	31	8		
Panthere	20	108	28	6		
Badine	6	66	18	4		

We may then proceed to fix the length of the keel, which will oblige us to determine the rake of the ftem and poft, for which the builders have given us no invariable rule, they being very much divided in their opinions, for where fome have given a rake of 18 or 20 feet, others have given none at all. The height of the ftem and wing-tranfom muft alfo be determined, which may be regulated by the decks.

The difference betwixt the draught of water abaft and that afore, fhould likewife be confidered; for though fome imagine that when a fhip is loaded her keel fhould be parallel to the furface of the water, yet in many cafes it will be found neceffary that the keel abaft fhould be deeper in the water that it is afore. This will give the rudder more power, and thereby contribute to make a fhip fteer well; but this difference of the draught of water is intirely arbitrary; for in large fhips fome have given five, whereas others have given but three, or even two feet of difference. Though I could not procure the true difference of the draught of water of many fhips of war, yet I am affured that the following are pretty exact.

The Difference of the Draught of Water in the following Ships.

	feet	in.		feet	in.
Northumberland	1	2	Panthere	1	4
Augufte	1	6	Couronne	2	1
Aloze	1	0	Triponne	2	
Hermione	2	0	Renommée	1	4
Amazone	1	6	Tigre	3	2
Badine	0	10	Intrepide	2	3
Palme	1	4	Alcide	2	0

The

The length of the wing tranfom muft alfo be determined; fome make it ⅐ of the main breadth; but this is likewife arbitrary, the broader a fhip is abaft, the more room there will be for accommodations for the officers; but this will be difadvantageous to her failing upon a wind.

The following Examples will be fufficient to fix the Length of the Wing tranfom for any Ship.

For a fhip of 110 guns, ⅓ of the main breadth, and 3 lines more to every foot.
102 guns, ⅔ of the main breadth, and 8 inches more.
82 guns, ⅔ of ditto.
74 guns, 7 inches, 9 lines for every foot in breadth.
62 guns, 7 inches, 8 lines for ditto.
56 guns, 7 inches, 7 lines, 9 points for ditto.
50 guns, 7 inches, 6 lines, 6 points for ditto.
46 guns, 7 inches, 6 lines for ditto.
32 guns, 7 inches, 5½ lines for ditto.
For a frigate of 22 guns, 7 inches 4 lines.
12 guns, 7 inches.

Some, without regarding thefe proportions, make the wing tranfoms of the firft and fecond rates two thirds of the breadth, and for all the reft one foot lefs.

After thefe dimenfions are determined, the timbers may be confidered which form the fides of the fhip. A frame of timbers is compofed of one floor timber, two or three futtocks and a top timber on each fide: All thefe being united together, and fecured by crofs-bars, form a circular inclofure, that which inclofes the greateft fpace is called the midfhip frame: The curve of this frame is inverted at the lower part, fo that the floor timber will be fomewhat hollow in the middle, whereby the ends will form a very obtufe angle; but this angle decreafes the farther the frames are removed from the midfhips, in fuch a manner, that the foremoft and aftermoft will become very fharp, and form a very acute angle. Thefe floor timbers are called crutches.

The builders feem to agree nearly as to the length of the midfhip floor timber, making it generally half the length of the main beam; but they differ very much about the rifing of it, fome chufing a flat and others a fharp floor. And if we confider the advantages and difadvantages that attend the one and the other, we fhall not be much furprized to find them fo much divided upon this article; for it is certain, the more rifing a fhip has, fhe will hold the better wind, but then this will occafion her to draw more water, which will be fometimes attended with very great inconveniences.

A Table

A Table of the rising of the Midship Floor Timbers.

Guns	f.	in.	lines.		Guns	f.	in.	lines	
110	0	0	10		56	0	1	4	
102	0	0	10½	to every foot in length.	32	0	1	4	to every foot in length.
86	0	1	0		28	0	1	4	
74	0	1	0		22	0	1	6	
62	0	1	0½		16	0	1	6	

Note, *What we have here rendered the rising of the floor timbers, the author calls the* Aculement, *and makes a distinction betwixt it and the rising, which we shall see when we come to form the frames.*

They differ as much in determining the station of the midship frame, some placing it before, others at the middle of the ship; others again have two floor timbers of equal length, and rising, one of which is placed exactly in the middle, or the breadth of the timber before the middle, and the other at a proper distance before it. Those who place it before, alledge, that if a ship is full forward, after she has once opened a column of water, she will afterwards meet with no resistance, and the water will easily unite abaft, and by that means force the ship a-head, and have more power on the rudder the farther it is from the centre of gravity; and besides this comes nearest the form of fishes, which should seem to be the most advantageous for dividing fluids.

Those who would have it placed in midships say, that by that means the water-lines forward will be easier, and of consequence properer for dividing fluids; and that there will be space enough betwixt it and the rudder for forming very fair water-lines, so that the water will easily unite at the rudder; and besides it will be easier by this means to balance the fore body and after body; and in general the building will by this means be very much facilitated; so that, in my opinion, it will be properest to place it very near the middle, though it is the general practice to place it before it.

After the rising of the midship floor timber is determined, we may then proceed to fix the height of the rising line of the floor abaft on the post, and afore upon the stem.

Now, as all ships are narrower abaft and afore, than in midships, the other floor timbers will of consequence be shorter and have a greater rising, which will be still increasing till it ends on the post and stem. There are several different methods used by the builders to settle the height of this line. Some imagine, that by narrowing the floor abaft, which will occasion the rising line to be high upon the post, the ship will

will thereby ſteer better, and beſides, the water which is opened by the midſhip frame will then have a greater preſſure upon the after part of the ſhip, and thereby contribute to her ſailing: Yet theſe arguments are of very little weight; for if we only conſider the ſteerage, it is certain, that the higher the riſing line is carried abaft, and the narrower a ſhip is, the water will have the eaſier paſſage, and more power upon the rudder. But then we ſhall thereby run the riſk of falling into two great inconveniencies; for, by this means, we take away the buttock, which is the only thing we have to ſupport all the weight of the after part of the ſhip; neither ſhall we be able to give a proper balance betwixt the fore and after part; and when the fore and after parts are not duly balanced, it will occaſion a ſhip to pitch very hard, and be in danger of being frequently pooped by the ſea when it runs high. To prevent theſe inconveniencies, it will be proper to give all ſhips, eſpecially the large ſort, a full buttock. As to the height of the riſing line afore, it ſhould be determined by the form of the water lines; but before this can be done, the timbers muſt be formed.

Note, What we have rendered the riſing line of the floor, our author calls les façons, *which, he ſays, is the increaſe of the* acculement, *the extreme points of which upon the perpendicular of the ſtem and poſt are now to be determined.*

The height of the lower deck is the next thing to be conſidered: It is determined in midſhips by the depth of the hold, and ſome builders make it no higher at the ſtem; but they raiſe it abaft more than it is in midſhips, as much as the load-water mark abaft exceeds that afore. As to the height betwixt decks, it is altogether arbitrary, and muſt be determined by the rate of the ſhip, and the ſervice that ſhe is deſigned for.

We come now to conſider the upper works, or all that is above water, called the dead-work: And here the ſhip muſt be narrower, ſo that all the weight that lies above the load-water line will thereby be brought nearer the middle of the ſhip; by which means ſhe will ſtrain leſs by working the guns, and the main ſail will be eaſier trimmed when the ſhrouds do not ſpread ſo much. But though theſe advantages are gained by narrowing a ſhip above water, great care muſt be taken not to narrow her too much, for there muſt be ſufficient room upon the upper deck for the guns to recoil. The ſecurity of the maſts ſhould likewiſe be conſidered, which requires ſufficient breadth to ſpread the ſhrouds, though this may be aſſiſted by enlarging the breadth of the channels.

C

CHAP.

C H A P. II.

Of the Scantlings and Dimensions of the principal Pieces of Timber in a Ship.

ALTHOUGH it is not my intention, as I observed in the beginning of the last chapter, to treat of all the pieces that compose the ship, yet I think it necessary to say something of the principal pieces. I shall therefore, in the following plate, lay down each piece by itself, by which means we shall see the length of the scarphs, and in what manner they are to be joined together.

Explanation of Plate I.

I.

A. The keel in four pieces, to be well bolted together, and clinched.

II.

I. The fore foot, one end of which is scarphed to the fore end of the keel, of which it is a part, and the other end makes a part of the stem, to which it is scarphed.

III.

u u. Two pieces of dead wood, one afore and the other abaft, fayed upon the keel.

IV.

C C. The stem in two pieces, to be scarphed together.

V.

E E. The apron in two pieces, to be scarphed together, and fayed on the inside of the stem, to support the scarph of the stem ; for which purpose the scarph of the apron must be clear from that of the stem.

VI.

o. The stemson in two pieces, to support the scarph of the apron.
o. The false post, which is fayed to the fore part of the post.

VII.

B. The stern post : It is tenanted into the keel, to which it is fastened with a knee.

D. The

VIII.

D. The back of the poft, which is likewife tenanted into the keel and well bolted to the poft; the defign of it is to give fufficient breadth to the poft, which feldom can be got broad enough in one piece.

IX.

F. The knee which fafteneth the poft to the keel.

X.

N. The wing tranfom. It is fayed acrofs the ftern poft, and bolted to the head of it: The fafhion pieces are faftened to the ends of it; underneath this and parallel to it is the deck tranfom.

XI.

O O. Two tranfoms faftened to the ftern poft and fafhion pieces, in the fame manner as the wing tranfom.

XII.

P. The tranfom knee, which fafteneth it to the fhip's fide.

XIII.

Q. The fafhion piece, of which there is one on each fide: Their heels are faftened to the ftern poft at the height of the floor ribbands, and their heads are faftened to the wing tranfom.

XIV.

T. A floor timber. It is laid acrofs the keel, to which it is faftened by a bolt through the middle.

XV.

K. The lower Futtock.

XVI.

T T T T T. 2d, 3d, 4th futtocks and top timbers. Thefe fhew the proper length and fcarph of the timbers in midfhips frame.

XVII.

U U. Riders. Thefe are fayed in the infide of the fhip, and confift of floor and futtock riders.

C 2				Z. The

XVIII.

Z.   The keelfon. This is made of two or three large pieces of timber fcarphed together in the fame manner as the keel. It is placed over the middle of the floor timbers, and fcored about an inch and an half down upon each of them.

XIX.

R S.   Breaft-hooks. Thefe are fayed in the infide to the ftem, and to the bow on each fide of it, to which they are faftened with proper bolts. There are geneally four or five in the form of R in the hold, one in the form of S into which the lower deck planks are rabbited; there is one right under the hawfe holes, and another under the fecond deck.

XX.

X, Y, Z.   are thick planks which are fayed in the infide, and ftretch fore and aft to ftrengthen the fcarphings of the timbers.

XXI.

Z.   are thick planks in the infide, called clamps, which fupport the ends of the beams.

XXII.

15, 15, 15, 15, 15, are the wales. They are planks broader and thicker than the reft, which are faftened to the outfide of the fhip in the wake of the decks. We fhall have occafion in another place to fhow how they are laid down in a draught. As to the plank below the wale to the keel, and above it to the top of the fide, we refer to the fection of one half of the midfhip frame, as laid down in the plate.

XXIII.

d, d, d, d, d, d, d, are knees.   Thefe are crooked pieces of timber confifting of two arms, which form an angle, either within or without a fquare, or exactly fquare; their ufe is to faften any two pieces together, as the beams to the fhip fides.

XXIV.

19.   The rudder.   This is joined to the ftern poft by the rudder irons, upon which it turns round in the googings which are faftened upon the ftern poft for that purpofe. There is a mortife cut out of the head of

it,

it, into which a long bar is fitted, called the tiller, by which the rudder is turned from one fide to the other.

XXV.

23. The cat heads. Thefe are two large pieces of fquare timber, one on each fide of the bowfprit. They project out before the bow, in order to keep the anchor clear of the fhip, which is hove up by a rope called the cat fall, that paffes through fhivers in the outer end of the cat-head : Their inner ends are faftened upon the forecaftle.

XXVI.

m, m, i, i, i, are the feveral pieces which compofe the knee of the head ; the lower part m is fayed to the ftem, the heel of it is fcarphed to the head of the forefoot ; it is faftened to the bows by two knees called cheeks, in the form of ƒ, and to the ftem by a knee called a ftandard, in the form of K.

XXVII.

Beams &c, a, X Y, are large pieces of timber which fupport the planks of each deck.

Having thus explained all the pieces in the plate, we fhall in the following table give their fcantlings.

SCANTLINGS of the principal Pieces of Timber in a SHIP.

BREADTH of the SHIPS.
LENGTH of the SHIPS.

NAMES of the PIECES.

BEAMS
- First deck square
- Second deck square
- Quarter deck and forecastle { Moulded, Sided }
- Poop { Moulded, Sided }

BREAST HOOK filed on the lower deck
CLAMPS, as broad as can be had, and half as thick as the timbers to which they are fastened.

KEEL { Deep, Broad }

KNEES
- Quarter deck and forecastle { Sided, Moulded }
- Second deck { Sided, Moulded }
- First deck { Sided, Moulded }

Planchere thick
Stem { Fore and aft, Thwartships }
Ditto, false or apron thick
STERN-POST { Fore and aft, Thick }

TRANSOM { Sided, Moulded }
Poop { Sided, Moulded }

TIMBERS
- Top timber { Broad, Sided, Out and in at the head, Out and in at the lower deck }
- Futtocks out and in at the lower deck
- Floor { Out and in at the head, Deep on the keel, Broad on the keel }

STERN-POST { Fore and aft { Below, Above } }

TRANSOMS
- Fashion-piece { Sided, Out and in { Below, Aloft } }
- Wing square { Moulded, Sided }
- Deck { Moulded, Sided }
- Second and third { Moulded, Sided }

WALES
- 1st and 2d { thick, broad }
- 3d and 4th { thick, broad }
- 5th and 6th { thick, broad }

Note, The Scantlings of the Knees moulded is ¾ from the Throat.
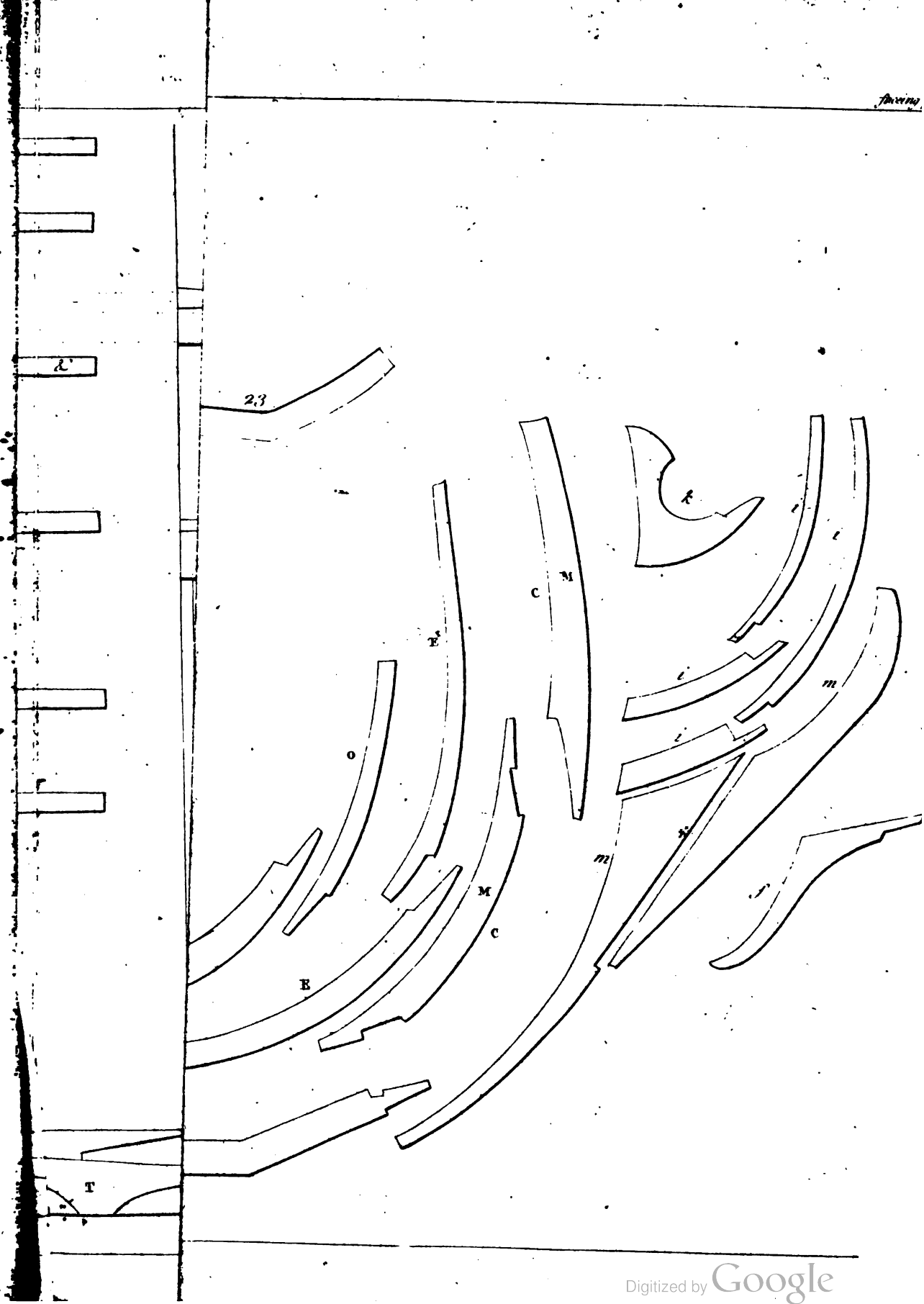
CHAP. III.

A Method to lay down a Seventy Gun Ship upon the Plane of Elevation.

THE Dimensions we have given of the principal parts of a ship of each class collected from the practice of different builders, which many have so great a regard to, as not to vary from them in the minutest article, we think only to be so far observed, as they shall produce such a form as the service the ship is designed for, shall require, agreeable to mathematical principles.

We shall now illustrate what has been said on that head by drawing a ship from these dimensions. But it will be first necessary to observe, that the builders make use of three different planes for one ship; 1st, the plane of elevation, in which the whole length is laid down according to a side view; 2d, The plane of the projection, which some call a vertical plane of the timbers, because it gives us an end view of the form of all the timbers, before the plank is put on. 3d, The horizontal plane, upon which are described all the curves that are formed by sections of the body parallel to the horizon, which must be considered as well as those vertical sections which form the curves of the timbers. We may likewise form the curves of the ribbands upon this plane, which will be of great use in proving whether the form we give the timbers will produce a fair side.

It is indifferent with which of these we begin, though that of the elevation seems most commodious. But first of all it will be very proper to draw out a list of all the dimensions of the vessel we are to build, so that we may have a view of the whole design.

This ship then is to have two tier of guns, so there must be two decks quite fore and aft, likewise a quarter deck as far as the main mast, a fore-castle 33 feet long, and a poop to the mizen mast.

There are to be 13 ports of a side on the lower deck, the guns to carry 24 lb shot; 14 ports on each side upon the upper deck, the guns to carry 18 lb shot; on the quarter deck 4 guns, and on the forecastle 2 guns of 8 lb shot on each side, and 2 of 4 lb on each side on the poop.

Ports.

	feet	in.	l.
Ports on the lower deck fore and aft	2	10	
Diſtance betwixt the ports	7	9	
Aftermoſt port from the poſt	9	3	
Foremoſt from the ſtem	17	2	
Height of the ſells, including the lower deck planks	2	5	
Ports up and down on the lower deck	2	7	
Diſtance from the upper ſide of the lower deck beam to the upper ſide of the upper deck beams	6	11	
Riſing of the ſecond deck abaft		11	
Second deck ports up and down	2	4	
Second deck ports fore and aft	2	6	
Height of the ſells from the deck line	1	11	6
Diſtance betwixt the ſecond deck and quarter deck from plank to plank	6	6	
Quarter deck ports up and down	1	10	
Quarter deck ports fore and aft	2		
Height of the ſells	1	4	
Diſtance betwixt the quarter deck and poop	6	2	
Ports on the poop fore and aft	1	10	
Height of the ſells	1	0	
Length from rabbit to rabbit on the gun deck	156	3	
Extreme breadth	42		
Depth in the hold below the plank	21	0	0
Riſing of the lower deck abaft, not including the difference of the draught of water	2	11	6
Height of the ſtem	31	9	3
Height of the poſt	31	7	9
Rake of the ſtem	15	7	2
Rake of the poſt	3	1	5
Length by the keel	139	6	10
Depth of the keel	1	7	3
Length of the wing tranſom	27		
Length of the midſhip floor timber	21		
Riſing of ditto	1	9	
Difference of the draught of water abaft more than afore	3	2	
Height of the riſing line of the floor abaft	13	6	0
Height of the riſing line of the floor afore	5	7	5

¶ I would adviſe young beginners in the art of drawing to conform exactly to theſe dimenſions, which we have here given for an example,

and

and obferve all the particular directions which we fhall give in laying down a fhip of 70 guns; for they muft begin by making themfelves acquainted with the terms, and thereby gain a general idea of the whole defign. After finifhing this draught, they may then proceed to another of a different rate, and as we have given the principal dimenfions of feveral good fhips, they may chufe fuch a one as will beft anfwer their defign.

Plate II. Fig. I.] 1ft. Provide a fcale of equal parts properly divided into feet and inches, adapted to the intended length of the draught, and draw the line A B, which make 156 feet 3 inches for the length of the gun deck, from the rabbit of the ftem to that of the poft.

To find the length on the gun deck, multiply 13, the number of ports, by 2 f. 10 in. the dimenfions of each port fore and aft, the product is

	f.	in.	l.
	36	10	0

Again multiply 7 f. 9 in. the diftance betwixt the ports, by 12, the number of fpaces, the product is

93	0	0

Aftmoft port before the poft	9	3	0
Foremoft abaft the ftem.	17	2	0
Length on the gun deck	156	3	0

2dly, Draw the line C D equal and parallel to A B, let 21 feet, the half of the main breadth, be the diftance betwixt them, and erect the perpendulars C F and D Z.

3dly, Set off 3 feet 2 inches, the difference of the draught of water, from B to G, and draw the line A G, which will give the pofition of the lower fide of the keel. From A fet off 1 foot 7 inches 3 lines, the depth of the keel, as in the table of fcantlings, to K, and draw the line K I parallel to A G, which will be the upper fide of the keel.

4thly, Set off 1 foot 3 inches 3 lines, the breadth of the ftem, from G to M, and draw the dotted line M N parallel to G Z. From G fet off 15 feet 7 inches 2 lines, the rake of the ftem, to O.

5thly, Set up 31 feet 9 inches 3 lines, the height of the ftem from G to P. With the radius I P defcribe the arch P O, which will be the fore fide of the ftem, and from the fame center defcribe another arch within the former, which will give the infide of the ftem, and another arch for the rabbit may be defcribed four inches before the infide of the ftem.

6thly, Set up 25 feet 1 inch from K to L for the height of the gun deck abaft, and 21 feet 6 inches from I to e, for the height afore.

7thly, Set up 2 feet 5 inches, the height of the port-fells from L to a, which will give the upper fide of the wing tranfom; from which fet up

D. 2 feet.

2 feet 7 inches, the height of the ports; alfo 1 foot for the depth, and 6 inches 9 lines for the round of the helm port tranfom, to the point F, which will be the height of the poft; fo K F will be 31 feet 7 inches 9 lines. From K fet off 3 feet 1 inch 5 lines to *f*, for the rake of the poft, and draw the line F *f* for the aft fide of the poft. From *f* to *b* fet off the depth of the keel, and draw the line *b d* for the fore fide of the poft, making F *d* ¼ of *f b*, fo fhall *f* O be the whole length of the keel.

The builders are very much divided about affigning a proper place for the midfhip frame, for which the following method may be ufed.

Divide the line C D into two equal parts, then take 5 feet 6 inches 10 lines, that is $\frac{1}{27}$ part of 156 feet 3 inches, the length of the gun deck: Set of this before the middle of the line C D, which will give the point F, the ftation of the midfhip frame. Set up 21 feet from F to Z, which will give the height of the gun deck at the midfhip frame. From the point Z fet off 2 feet 7 inches 6 lines (the ⅛ of the height of the gun deck at the midfhip frame,) through which point draw a line V T, parallel to C D, which will be the load-water line. Through the point F draw the line G *g*, parallel and equal to the load-water line, which will fhew how much water the fhip will draw abaft more than afore.

One of the frames is placed pretty near the chefs tree, which is called the loof frame; to find its place, from the point D fet off ¼ of the line D C, and there draw a dotted line perpendicular to A B. Again divide the line F G into nine equal parts, and draw eight lines perpendicular to A B, which will ftation eight frames in the fore-body befides that of the loof.

There is in the after-body a frame to balance that of the loof in the fore-body; thefe two are of equal breadth in fome points, and this will occafion the center of gravity of that part contained betwixt thefe two frames to be near the plane of the midfhip frame, which will keep the fore part and after part upon a balance. It muft be as far abaft the middle of the line C D as that of the loof is before it.

The frames in the after-body are the fame diftance from one another as they are in the fore, which will occafion one more abaft than before; fo there are nine abaft, befides that of the balance.

We fhall in the next place lay down the deck lines, and firft for the lower deck draw a fair curve through the points L Z *e*, and parallel to it draw another curve for the port-fells, which are 2 feet 5 inches above the deck line.

The

The aftermost port is 9 feet 3 inches before the post, which set off to *n*, and the ports are 2 feet 10 inches fore and aft; which set off from *u* to *x*, the distance betwixt the ports is 7 feet 9 inches, which set off from *x* to Y for the aft side of the second port; from Y again set off 2 feet 10 inches, which will give the foreside of the next. Proceed in the same manner till all the ports are spaced; so shall the foremost port be 17 feet 2 inches abaft the rabbit of the stem. The height of the ports is 2 feet 7 inches, which set up from *u*; draw a curve parallel to the deck line, which will give the upper part of all the ports; after which these two lines may be wiped off the draught, which must be therefore drawn with a black lead pencil, and only the ports inked in.

Draw a line for the upper deck, which is 6 feet 11 inches above the lower from the midship frame forward, and 6 inches more abaft. We may then draw a line for the port-sells, and one for their height, parallel to the deck line, and space the ports so that they may be exactly over the middle of the distance betwixt the lower deck ports.

Before we can set of the height of the quarter deck we must find the true place of the main mast. The general rule is to take 4 lines for every foot the gun deck is in length, and set it off abaft the middle, which will give the foreside of the mast, now the length 156 feet 3 inches × 4 lines = 625 = 4 feet 4 inches 1 line, which set off abaft the middle of the line C D, and there erect a line perpendicular to the water-line, which will be the fore side of the mast; and parallel to it draw a line for the middle, and one for the aft side of the mast, the diameter of which is 35 inches. Set off 6 feet 6 inches on the aft side of the main mast, for the height of the quarter deck afore, and 6 feet 10 inches for the height abaft; and draw a line nearly parallel to that of the upper deck, which will be the line for the quarter deck. We may then space the ports, so that they may be exactly over those of the lower deck. The forecastle is 6 feet 6 inches high, at which distance draw a line parallel to the upper deck line, which will give the line for the forecastle deck. As to the length of this deck, it ends forward at the beak head, and is carried aft discretionally, observing to leave room for the capstan bars. In spacing the ports upon the forecastle, care must be taken that none be opposite to the fore mast. Now to find the center of this mast, take 15 feet 7 inches 2 lines, the tenth part of the whole length, which set off from the rabbit of the stem upon the lower deck abaft, from which point set off 32 inches and 1 line, being the diameter of the mast; through the middle of this draw a perpendicular line, as in the plate. The boltsprit generally makes an angle of 34 or 35 degrees with the load-water line.

D 2   The

The poop is pretty near parallel to the quarter deck; the distance betwixt them forward is 6 feet, and abaft 6 feet 3 inches. It ends about 18 inches before the mizen maft, the aft side of which is $\frac{2}{7}$ of the main breadth before the rabbit of the post upon the gun deck.

The counter is generally an arch paffing from the upper side of the wing-tranfom to the lower side of the beam of the fecond deck. The rake of the lower counter is $\frac{2}{7}$ of an inch for every foot of the main breadth. The rake of the fecond counter is $\frac{2}{7}$ of the lower; its height above the deck is 3 feet 5 inches. The hollow of the counters is altogether arbitrary, infomuch that fome give none to the lower. The upright of the stern rakes 2 inches in a foot, as in the plate.

The beauty of a fhip depends much upon giving the wales a proper hanging; for by them the sheer and drift rails are regulated, being all nearly parallel to one another, though they generally rife a little more abaft on account of the accommodations for the officers. It is this which makes a fhip look airy and graceful in the water. There is no certain rule for laying them down; this is left entirely to the fancy and tafte of the artist; but in placing the wales great care muft be taken that they be wounded as little as poffible by the ports; the foremoft port on the gun deck muft be $1\frac{1}{2}$ or 2 inches above, and the third port from abaft juft touch the upper side of the upper ftrake of the main wales. The lower edge of the lower ftrake may glance with the edge of the water when loaded. There are two ftrakes of wales, and one ftrake between them of 15 inches broad each. The range of the deck fhould be confidered in placing the wales, fo that the fcuppers may be in the ftrake betwixt the wales. The like caution muft be ufed for the channel wales as may be feen in the plate, where they are all laid down, together with the sheer and drift rails; the rails, cheeks, and knee of the head are likewife laid down in the plate, and being for an ornament to the fhip, are left to the fancy and tafte of the builder. Though the knee may help a fhip to hold a good wind, the fore part of it is generally one twelfth part of the length before the stem.

CHAP.

CHAP. IV.

To lay down the Frames upon the Plane of Projection.

HAVING thus explained all that is neceffary to be delineated upon the plane of elevation, the next thing to be determined is the different breadths of the fhip at any affigned points of the length, whereby we fhall gain the forms of all the planes that are made by fections, perpendicular to the load-water line. The timbers that compofe the body of a fhip are fuppofed to have their planes in that pofition, and may be all delineated upon the plane of the projection; but as both fides of a fhip are exactly the fame, it will fuffice to lay down the half of each, thofe of the fore-body on the right, and thofe of the after-body on the left hand. And whereas thefe planes diminifh afore and aft, the planes of all the frames may be all delineated upon the plane of the midfhip one, which may be called the mafter-frame. The firft thing then neceffary to be known, is how to form this frame.

The mid-fhip frame is that which is at the broadeft part of the fhip. The builders differ about the form of this frame, but there are feveral preliminary operations which are neceffary to be obferved in all the different methods ufed in forming it.

Preliminary Operations for forming the Midfhip Frame.

Plate III, *Fig.* I. *and* II.] ift. Draw the line A B to reprefent the upper fide of the keel; it muft be at leaft as long as the fhip is broad. This line our author calls the line of *aculement*, becaufe upon it the aculement of the midfhip floor timber terminates.

2dly, Draw the line C D parallel and equal to A B, fo that A C and B D may be equal to the rifing of the midfhip floor timber. This line may be called the rifing line, becaufe it limits the height of the ends of the midfhip floor timber above the keel.

3dly, Draw the line G H, for the height of the lower deck, parallel to the former; and below this, draw a line to reprefent the load-water line, taking its diftance below the deck line from the plane of elevation at the midfhip frame. Draw alfo the lines I K and L M, the one for the fecond deck, and the other for the fheer rail or top of the fide in midfhips. The height of both are to be taken from the plane of elevation.

4thly,

4thly, Draw the line N O perpendicular to A B; this is called the middle line, and reprefents the middle line of the ftem and poft, dividing the whole fhip into two equal parts; and parallel to N O draw the lines A L and B M, to limit the breadth; alfo a line for half the thicknefs of the ftem, and one for half the thicknefs of the poft. Draw the lines z x parallel to N O, dividing the lines O A and O B into two equal parts. Draw alfo the diagonal G B. Thefe lines being drawn, we may proceed to form the midfhip frame by fome of the following methods.

METHOD I.

To form a Midfhip Frame, that fhall be neither too fharp nor too flat.

Plate III. *Fig.* I.]　　1ft, Divide the line a x, which marks the head of the floor timber into three equal parts; fet off one from a to b.

2d, Divide the line d B, the diftance betwixt the load-water line and the upper fide of the keel, into feven equal parts; fet off one of thefe from d to e, and from e to m, and draw the diagonal a V, which divide into two equal parts in the point n. *Note, the diagonal, a V, is wiped out, after finding the point n.*

3d. Defcribe an arch of a circle to pafs through the points b and e; make the radius the whole length and half the length of the line B e, fo the center A may be found by defcribing an arch with that radius from e, and one from b to interfect one another in A, we fhall only make ufe of that part of this arch betwixt l and m. Now, to find the other arches m d, l a, a n, n V, it muft be obferved, that, in order to reconcile two arches, fo as to make a fair curve, a ftrait line muft pafs through the centers of both, and through the points where they unite or touch one another; draw therefore the lines A m and A l, fo fhall k be the center of the arch m d, and o the center of the arch l a. Again, through the center o draw the line a o, produce it to P, which will be the center of the arch a n. Laftly, from P thro' n draw the line P s, s will be the center of the inverted arch n V. *Note, the center s will be without the Plate.*

4th. To form the top timber, fet back the tenth part of the half breadth from K to S, upon the line of the fecond deck; defcribe an arch of a circle thro' the points d and S, taking ⅓ of the whole breadth for the radius: Again, from the point M, upon the line L M, fet back the fifth part of the whole breadth to l. Defcribe an arch of a circle thro' the points S and l, taking the diagonal G B for the radius. As this arch is inverted in refpect of the arch d S, the center will be without the figure. This compleats the form of half the midfhip frame, and by the fame operations we may find the other half.

It muft be obferved, that there is no regard had to the round of the beam in fetting off the deck line or depth of the hold.　　M E-

METHOD II.

To describe a Midship Frame of a circular Floor.

Plate III. *Fig.* II.] From the center G, the point where the middle line intersects the deck line, making the half breadth the radius, describe the arch *b*, G, *c*, O: Let *d* be the head of the floor timber, and *d x* the rising. Assume the point *f*, according to what round you propose to give to the second futtock, and describe the arch *d f*; the center may be found as directed in the preceding method. Divide the arch *c* O into three equal parts; set off one from *c* to *g*, and from the center *b*, describe the arch *d g*; there remains only the inverted arch *g* Y to be described; the center may be found as before directed.

METHOD III.

To draw a Midship Frame which shall be full.

Plate III. *Fig.* III.] 1ft. Draw the rising and deck lines as before; let *b x* be the rising.

2d. Make *d b* the side of the square *d b a c* equal to C *b* the ¼ of the breadth.

3d. Inscribe the two quadrants *c e b*, and *c f b*, into the square.

4th. Divide the side *c a* into a certain number of equal parts in the points O, N, M, L *a*; draw the lines *i* L, *b* M, &c. perpendicular to *a a*.

5. Divide the line C G, the depth of the hold, after deducting the rising, into the same number of equal parts in the points E, F, I, K, and make the lines E *p*, F *q*, I *r*, K *s*, in the frame, equal to the lines O *i*, N *n*, M *e*, L *m* in the square, describe a curve through the points G, *p*, *q*, *r*, *s*, *b*, and the remaining part of the frame may be described by the preceding methods.

METHOD IV.

To describe a Midship Frame for a very sharp Ship.

Plate III. *Fig.* IV.] Let the length of the floor timber be half the breadth as before, and the rising one fifth or one sixth of the whole length of the floor timber; lay this off from *x* to E, and describe a parabola through the points G, P, Q, E, of which the point G is the vertex, and G C the axis. This method is extracted from M. *Bouguer*. The parabola may be formed by the following method: 1. Through the point E draw the line T *x* perpendicular to G C, and the line *d* E perpendicular to A G, and

produce

produce the line C G to D. 2dly, Upon the line C D find the center of a femicircle that fhall pafs through the points T, *d*, and D, fo fhall G D be the parameter of the parabola, by which we may find any number of points through which the curve muft pafs: For inftance, fuppofe it were required to find a point in the perpendicular X P, through which the curve muft pafs; upon the line G D find the center of a femicircle which fhall pafs through the points D and X; this will interfect the line A G in *b*, make *b* P equal and parallel to G X, fo fhall P be the point required; in like manner, the points *a* Q *f* may be found. The remainder of the curve from E to *y* will be compofed of two arches, the one to reconcile with the parabola in the point E, and the other inverted to pafs through the point *y*; the center of which may be found by any of the preceding methods. In order to find the center of that which joins with the parabola, make T R equal to half the parameter G D, and draw the line E R, upon which find a point S for the center of the arch.

We might fhew a great many more methods of defcribing this midfhip frame. It is very true, that great care ought to be had in forming this frame, becaufe upon it chiefly depends the form of all the other timbers; I fay chiefly, but not altogether; for two fhips may be fimilar as to their midfhip frames, and yet very different afore and abaft; and though the artifts fhould make themfelves acquainted with all the different ways of forming this frame, I fhould recommend that method to them which is the fimpleft, and which gives them the moft liberty to vary the form of it, according to every one's particular tafte or fancy; and it is very poffible there may be feveral other methods as eafy and plain as thofe we have defcribed. This frame being once formed, we may form all the reft upon the fame plane. We fhall, in the next place, fhew the different methods ufed by the builders for that purpofe.

The ancient builders, not being acquainted with the methods of laying down their defigns in a draught, found out a mechanic way of doing this, only by help of the midfhip frame, which they might have formed by fome of the preceding methods, or any other contrivance of their own; and though this method is defective in feveral points, yet as it is an ingenious contrivance, we fhall give it a place here.

METHOD I.

Of forming the Timbers by a Mould made to the Midfhip Frame; a rifing Staff and overcaft Staff.

Plate III. *Fig.* VII.] 1ft. Having formed the midfhip frame, and fet off its fcantlings, make a mould to fit both outfide and infide, which may be called the bend mould.   2d.

2d. Draw the line Z *x* to limit the head of the floor timber at *d*; let *d u* be the rifing, and draw the line *a u*; let *t* be the height of the rifing line abaft, and draw the line *d t* to reprefent the floor heads, or floor ribband. Set off *d x* from *d* to H; and from *e*, the head of the firft futtock, to 6, and divide each in fix equal parts, being the number of frames from midfhips to the balance frame.

3d. Divide the line *a u* into five equal parts, and fet off two of them from *a* to S; divide the line *a* S into the fame proportion, that the part A 6 of the bafe A C of the right angled triangle (*Fig. 5.*) is divided into, and transfer thefe divifions to the bend mould, and let them be numbered 0, 1, 2, 3, 4, 5, 6, which points will give the narrowing of the floor, as we fhall fhew, after conftructing the triangle. We fhall only remark, that the line *a* S, which is $\frac{2}{5}$ of *a u*, is nearly the difference betwixt half the length of the midfhip floor timber, and half the length of the floor timber at the balance frame. But as this appears to be too much, we may take $\frac{2}{5}$ as in the figure, or any other quantity which fhall be thought moft convenient.

To conftruct the Triangle, Fig. 5.

Upon the line A C, drawn at pleafure, fet off any diftance from A to 1, and double that diftance from 1 to 2, treble from 2 to 3, and fo on in the fame progreffion till we have as many divifions on the line A C as we propofe to have frames abaft the midfhip. Erect a perpendicular at A, which may be produced at pleafure, and from any point B draw lines to all the divifions of the bafe A C. Obferve, that though in the triangle we have drawn a line for every frame to the fafhion piece, we fhall only make ufe of fix, there being fo many to the balance frame. The triangle being thus conftructed, apply the line *a* S to it, in fuch a manner, that it may be parallel to A C, and be contained betwixt the lines B A and B 6, the lines drawn from the point B to the points 1, 2, &c. will divide it into the required proportion.

To conftruct the Rifing Staff, Fig. 5.

This ftaff K L may be of the fame breadth with the keel, and a little longer than *a t*, the height of the rifing of the floor. In order to graduate that ftaff, fet off *x u*, the rifing of the midfhip floor from K to *o*, and make *o* L equal to *a t*; apply the line *o* L to the triangle, fo that it may be parallel to the bafe, and contained betwixt the lines A B and B C the

<div align="center">E</div>

<div align="right">lines</div>

lines from the point B to the feveral points in the bafe will divide it into the required proportion, which will give the rifing of the floor.

Note, Our author calls x u *the acculement, and* u d *the rifing ; the line* u a *will pafs through the point where the inverted arch joins the floor fweep.*

To conftruct the over caft Staff, Fig. 5.

That we may have a clear underftanding of what is meant by over-caft, it will be proper to obferve, that in forming the frames by the bend mould, when it is fet to the narrowing of the floor, the head of the mould will come too far in at the deck ; the mould muft therefore be moved round upon the point which reprefents the floor ribband, till the head goes out to the proper breadth ; this will occafion the lower part of the mould to rife a certain quantity, which is called the over-caft. In order to graduate this ftaff we muft determine the difference betwixt the main breadth at the midfhip frame, and at the balance frame, which fuppofe D F, let this be placed parallel to the bafe, and contained betwixt the line B A and B 6 ; fo fhall the lines B 6, B 5, &c. divide it into the required proportion.

Thefe are the inftruments that are neceffary for forming the after frames, thofe for the fore part are conftructed in the fame manner, only the graduations for thefe are but half the graduations of the former, for which reafon there muft be another bend mould graduated for the forebody.

Now, in order to form the frames by thefe inftruments, place the bend mould upon the rifing ftaff in fuch a manner that the middle line of the ftaff produced may pafs through the narrowing of the floor upon the bend mould, expreffed by the divifion correfponding to the frame to be formed ; fuppofe frame 6, (*Fig. 7.*) the lower or ftrait part of it expreffed by the dotted line in the figure being applied to the rifing ftaff, till the middle line B a pafs through the divifion 6 on the bend mould : mark by the edge of the rifing ftaff the point 6, which expreffes the rifing of the floor at that frame. Set up the over caft (expreffed by the fpace contained betwixt the points 5 and 6 upon the over caft ftaff) from the lower part of the bend mould to the point 6 upon the line B a ; then keeping the point d immoveable, turn the bend mould upon this point till the lower part rife to the over caft at the point 6, upon the line B a, and when in this pofition we may defcribe the curve to the floor head, and then invert the bend mould, and placing the point 6 (betwixt d and H) to the point fet off before to exprefs the rifing, turn the mould

till

till the ftrait part touch the curve before defcribed, and then draw the lower part, which compleats the frame.

This is the method that is ufed when they mould the timbers, and it may likewife be ufed to lay them down upon a draught; for if the line *a u* of the bend mould (*Fig.* 8.) be laid upon the line A V, we may, when in that pofition, defcribe the midfhip frame from the point *d* to the point *x*. In like manner we may defcribe all the reft of the frames, by giving each its proper over-caft and rifing; as for inftance, if it were required to defcribe frame 6, take the rifing K 6 upon the rifing ftaff, and fet it off from the point B to the point *a* upon the line B G, and draw a line through the point *a* parallel to A V, upon which laying the bend mould in fuch a manner that the point 6, which expreffes the narrowing of the floor, fhall be upon the point *a*; then will the point *d* be upon the point R : Set up the proper over-caft from *a* to 6, and keeping the point *d* immoveable, pufh up the bend-mould, which at firft was placed at the point *a*, till it be raifed to the point 6, which will throw out the point *x* to the proper breadth at the deck. But be-caufe the deck is higher at timber 6 than at the midfhip frame. Take the diftance betwixt *e* and 6, at the head of the futtock on the bend mould, and fet it up from *x* to 6, and then inverting the bend mould, fo that the point 6 betwixt *d* and H be at the point X, and the ftrait part of the mould touch the curve before defcribed : we may then defcribe the lower part to the point X, which compleats the whole frame. The tim-bers for the fore body may be defcribed by the fame procefs as thofe of the after body, only making ufe of the bend mould, rifing, and overcaft ftaff, graduated for that purpofe; but, as we obferved before, we cannot lay down any timbers by this method, but thofe betwixt the midfhip and ballance frame.

The builders finding how very advantageous it would be for them to form all the timbers upon the plane of the projection, becaufe they could then at one view fee how they would compare one with another, have tried feveral expedients to perform this, of which I might inftance ten or twelve, but fhall content myfelf with explaining three, which may be fufficient for thofe purpofes, in order to which I fhall firft fhew another method of forming the midfhip frame, different from thofe we have fhewn before.

Plate III. *Fig.* 6. 1ft. Draw the rifing deck, and load-water lines, and fet off the length of the floor timber as before.

2d. Take one fourth of the length of the floor timber, and fet it off from O to *d*, upon which erect the perpendicular *d c*, and divide it into two equal parts in the point *e*.   E 2   3d.

3d. Defcribe an arch through the point *a*, the head of the floor timber, and the point *e*, taking for the radius the diftance from the upper edge of the keel to the port-fells, or a little more or lefs, according to what round you propofe to the floor head. This determines the rifing of the floor timber, and with the radius O *l*, half the length of the floor timber, defcribe the arch *e* Y, which determines the *aculement* of the floor timber.

4th. At the point *l*, the middle of the line A O, erect the perpendicular *l m*; and at the point *n*, the middle of the line A *l*, erect the perpendicular *n o*; erect alfo the perpendicular *p q* at the middle of the line A *n*; and another *r s*, at the middle of the line A *p*; and laftly, another *t u*, at the middle of the line A *r*.

5th. Take the diftance *l n*, which fet off on the line *n o* from *n* to *z*; and on the line *p q*, from *p* to *g*; then taking the diftance from *a* to *g*, fet that off from *p* to *y*; again take the diftance *p y*, which fet off from *r* to *b*, and the diftance *b a* from *r* to F; and laftly take the diftance *r* F, which fet off from *t* to E, and then the diftance E *a* from *t* to X, a curve paffing through the point *a*, *z*, *y*, F, X, T, will form the midfhip frame under water. We may then fet off half the thicknefs of the poft and ftem on each fide off the middle line, and form the reft of the timbers; thofe for the fore body on the right, and for the after body to the left of the middle line.

Plate II. 1ft. To lay down the poft upon the plane of projection, take the difference of the draught of water abaft more than in midfhips, as marked on the plane of elevation (*Fig.* 2.) fet off this from F to *e*, (*Fig.* 3.) and draw the line *d e* parallel to A B; take alfo K F, the height from the plane of elevation, which fet off from *e* to *r*, fo fhall the point *r* be the head of the poft.

2d, To lay down the wing tranfom, take its height from the plane of elevation, which fet up on the plane of projection to *f*, and draw the line *g f* perpendicular to the middle line, fo *g f* reprefents the upper fide of the wing tranfom, without regarding the round up or the round aft. Take alfo the height of the rifing line upon the poft from the plane of elevation, which fet off from *e* to G.

3d. To form the fafhion piece; take upon the plane of the projection *n* G the height of the load-water line, above the rifing line upon the poft, which fet off from *n* to *o* upon the water line; take alfo G P, the diftance betwixt the rifing line and lower deck, which fet off from P to *q* upon the deck line, and defcribe a circle through the points *f*, *q*, *o*. There is a problem in geometry to find the center of this arch. *Note*, the point *q* may be taken further out or in, as you defign a lank or full fafhion piece.

Laftly,

Laftly, defcribe the arch *v* G ; the radius of this arch may be the main half breadth ; fo fhall *f, q, o,* G, be the form of the fafhion-piece, which may be varied according to the fancy of the artift, by altering the centers.

Having thus formed the midfhip and after-frames, we fhall, in the next place, fhew how to fpace the ribband lines, which are reprefented by the diagonals in the figure ; but it will be proper to remark, that the ribbands are thin narrow planks, which are made fo, that they may eafily be bent to the timbers. That which is nailed to the poft at the height of the rifing line, and to the midfhip frame, at the end of the rifing of the floor timbers, is called the floor ribband. That which anfwers to the wing tranfom and to the height of the lower deck, on the midfhip frame, is called the breadth ribband ; all the reft betwixt thefe two are called intermediates.

From the point H draw the line H G for the floor ribband, and from the point T draw the curve T, E, *q, p* for the breadth ribband, and draw the two intermediates betwixt them, fo that by them the curve of the midfhip frame and fafhion piece may be divided into three equal parts.

Now, it is very plain, that if the ribbands had a proper form, and nail'd at the proper heights and pofitions, they would compofe a kind of a model, by which the circular form of every timber might eafily be dif-covered ; but as we have only the extreme points of each given, we cannot from thence form fuch a curve as fhall be neceffary. We muft therefore find a method to form fome intermediate timbers betwixt the midfhip and after one, and thereby form the ribbands fo that they fhall make fair curves. There are fome preliminary operations which are ne-ceffary towards performing this.

1ft. *To conftruct an equilateral Triangle for the Progreffion of the Frames in the After-Body.*

Plate IV. Fig. I.   From the point M fet off any diftance to 1, upon any ftrait line, and from 1 to 2 treble that diftance, from 2 to 3 five times that diftance, from 3 to 4 feven times that diftance, and proceed in that progreffion, increafing the fpaces betwixt the figures by equal differences, *viz.* double the diftance betwixt M and 1, till we have as many divifions lefs one as there are frames betwixt the midfhip and poft, including that of the midfhip and poft ; and becaufe there are nine frames the line muft confift of ten divifions, from the point M to the point E. Let them be numbered 1, 2, 3, &c. make M E the bafe of an equilateral trian-gle S M E, and draw the lines S 1, S 2, &c. obferving to produce them all till the diftance betwixt the lines S E and S 9, upon a line parallel to the bafe, be at leaft equal to the diftance betwixt the frames in the plane

of elevation. The line S M reprefents the midfhip frame, and the line S E, the poft, and the nine intermediates reprefent the nine frames betwixt the midfhip and poft.

In order to give us a clear underftanding of the ufe of this triangle, it will be neceffary to remark, that the midfhip frame being that which inclofeth the greateft fpace, and the aftermoft that which inclofeth the leaft, it will follow, that the intermediate frames will partake of the form of each, but moftly of that to which they are neareft; yet they will ftill retain a little of the form of each. Hence, when the intermediate frames are all formed, their curves will divide all the diagonals, drawn in the plane of projection, into as many parts as there are frames; and all the methods the builders have invented ferve only to divide them into fuch a proportion as fhall produce the faireft curves.

Now, if the proportion pitched upon for that purpofe, be as 1, 3, 5, 7, 9, &c. then they muft all be divided into the fame proportions as the bafe of the triangle is divided into; and this may be performed very readily, only by taking the length of each diagonal from the plane of the projection, and applying it to the triangle in fuch a manner that it fhall become the bafe of an equilateral triangle; as for inftance, to divide the firft intermediate diagonal, take the length of it in the plane of projection, (*Plate* II. *Fig.* 3.) and fet it off from the point S to *m* and *k* on the fides of the triangle S M and S E; and draw the line *m k*, which being parallel to the bafe of the triangle, will be divided into the fame proportion. In like manner, all the reft of the diagonals may be divided; but as the builders are not agreed as to the precife form of a fhip's bottom, fome chufe to divide the bafe of the triangle into another proportion; others again, in applying the diagonals to the triangle, give them different inclinations to the line M S. It would be very proper to try feveral of thefe methods, by which means we might difcover which would be moft convenient; and after all the diagonals are divided into as many points as there are frames, curves paffing through thefe points will determine the form of all the frames from the midfhip to the poft. It only remains to fhew how to end each frame upon the poft. It was before obferved, that the keel is not parallel to the furface of the water, fo that it will be very eafy to conceive that the height of each frame, taken from the upper fide of the keel, upon a perpendicular to the furface of the water, will always increafe, the nearer the frame is to the ftern poft. Now, *g* K is what the keel is deeper abaft than at the midfhip frame; and to find how much any frame abaft exceeds that of the midfhip, fuppofe the firft; take the diftance betwixt the line *g* G and K I at that frame, from the plane

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of elevation, (*Plate* II.) which set off from F towards *d*, *(Fig.* 3.) and at that point draw a line parallel to *d e*, which will be the first frame upon the keel. In like manner we may draw lines parallel to *d e*, for all the rest, as in the figure, which will determine their heights from the upper side of the keel to the surface of the water.

It muft be obferved, that the diagonals in the plane of the projection, which end on the fafhion piece, muft likewife end on the fafhion piece on the plane of elevation; we muft therefore draw the fafhion piece on the plane of elevation. Thus, take the diftance of the point G, in the plane of the projection, from the upper fide of the keel, which fet off upon the ftern poft in the plane of elevation to the point *b*; through *n*, the rabbit of the wing tranfom, draw the ftrait line *b* M, which will reprefent the fafhion piece on the plane of elevation. Now, as only the loweft diagonal ends upon the poft, in the plane of projection, which in the plane of elevation ends at *b*, fo the other diagonals that end upon the fafhion piece, muft likewife end on the fafhion piece in the plane of elevation. Their height muft therefore be transferred from the plane of the projection to that of the elevation; fo the fecond diagonal will end at the point P, upon the fafhion piece in the plane of elevation. In like manner all the reft may be transferred to the plane of elevation; and as the line that reprefents the fafhion piece upon the plane of elevation rakes aft, this will occafion the line P S, which is perpendicular to the line that reprefents frame 9, to exceed the line *b* M. In the triangle, the line S M reprefents the midfhip frame, and the line S E the poft; that is, if the point where the ribband ends on the poft, be equally diftant from frame 9, that frame 9 is from frame 8. Now, as M *b* is longer than M L, we muft draw the line S D without the triangle, which is to be ufed inftead of the line S E, when we come to apply the diagonal H G to the triangle; for the point H muft touch the line S M, and the point G the line S E. To find the point D, take M L from the plane of elevation, and apply it to the triangle, fo that B C fhall be equal to it, and parallel to M E; it muft alfo be contained betwixt the line S 9 and S E. Then take *b* M, and fet it off from B, which will give the point D. In like manner the line S F muft be ufed, when we divide the diagonal M K; and to find the point F, fet off P S, in the plane of elevation, from B to F in the triangle; and draw the line S F. In the fame manner there muft be lines drawn for every

Plate IV. *Fig.* 1.] diagonal without the line S E; fo the line S E is not ufed in dividing the diagonals. Let it be further obferved, that in applying each diagonal to the triangle, it muft not only be contained betwixt the line S M, and the line correfponding to the diagonal, which is to be divided, but it muft likewife form a certain angle with the line M S,

that

that is, with that part of it which is intercepted betwixt the diagonal and the point S. Thefe which appear to me to be propereft for that purpofe are as follows: The firft diagonal to make an angle of 60 degrees; the fecond 62½, the third 68, the fourth 86, the fifth 65, the fixth 60 degrees; but the artifts vary thefe angles according to the form they defign to give to the timbers; nay, fome draw them always parallel to the bafe of the triangle.

Our author then proceeds to the forebody, and forms a triangle, the bafe of which he divides in the fame manner as that already defcribed, by which he divides each diagonal. He likewife fhews how to fpace the diagonals upon the ftem; but as the artifts leave us fo much undetermined as to the angles that each diagonal is to make with the line S M, when they are applied to the triangle, it will be very difficult to apply this method to practice. So we prefume it will be needlefs to fay any more on that head; judging what has been already faid fufficient to give our readers an idea of the principles on which the method is grounded; we fhall proceed therefore to the next method he propofes.

To form the Timbers by a Quarter of a Circle. Plate IV. Fig. 2, 3.

1ft. Form the midfhip frame, the fafhion piece, the foremoft timber, alfo the two balance frames, by fome of the preceding methods. *Note, Thofe who make ufe of the following method of forming the reft of the timbers, are fuppofed to be previoufly acquainted with the manner of forming the midfhip frame,* &c.

2d. Space all the diagonals for the ribbands as directed in the preceding method.

3d. From the center A, with any radius, defcribe a quarter of a circle, and divide it into fo many equal parts, that there may be a point for each timber to be formed, and draw the radii A 1, A 2, &c. to A 9, fo we fhall have one for each frame.

4th. Take *a b*, the firft diagonal, which fet off from the point A upon the line A C, to 1.

5th. Take *a c*, the diftance upon the lower ribband, betwixt the poft and balance frame, which in the plane of projection is the 6th frame, fet off this diftance upon a perpendicular erected upon the line A B, to interfect the radius A 6, in fuch a manner that the perpendicular G 1 fhall be equal to *a c*.

6th. Produce the line C A to F, and upon this line find a point, which fhall be the center of a circle whofe circumference fhall pafs through the point 1, before marked upon the line A C, and the point 1, now marked upon the radius A 6; defcribe the arch through thefe two points to the point 1 on the line A B.

7th.

7th. Let fall perpendiculars to the line A B from the points where the arch 1, 1, 1, interfects the feveral radii. Transfer thefe perpendiculars to the line *a b*, which will divide the lower diagonal into the points through which the curves of the frames muft pafs. *Note, the perpendiculars are not drawn, to avoid confufion.*

After the fame manner all the other diagonals are graduated, firft by taking the whole length of each diagonal, and fetting them up on the line A C, from the point A to the points 5, 4, 3, 1, 2, and fecondly, by taking the feveral diftances upon each diagonal intercepted betwixt the after frame and the balance frame, and applying them feverally to the radius A 6, in fuch a manner that they fhall be contained betwixt the radius A 6 and the line A B, upon the perpendiculars let fall from the points 5, 4, 3, 1, 2. And, thirdly, by defcribing arches through the points in the line A C, to pafs through the points of the fame number upon the radius A 6, whofe centers are in the line A F; the arches to be produced to interfect the line A B in the points 5, 4, 3, 1, 2, will interfect all the radii; the perpendiculars let fall from the interfections of the radii with the arch correfponding to each diagonal, will divide that diagonal into the points through which the curves of the frames muft pafs.

The diagonals for forming the frames in the fore body are divided into the points through which the curves muft pafs by the fame operations, only obferving that frame 4 is the ballance frame for the fore body.

C H A P.   V.

Of the Projections on the horizontal Planes, and of the Water and Ribband Lines on the Plane of Elevation, and that of the Projection.

WATER Lines are defcribed upon a fhip's bottom by the furface of the water into which fhe fwims; that which determines how much is under water when fhe is loaded is called the load-water line. Now it is plain, that if a fhip is lightened, fhe will rife higher out of the water; and if fhe be lightened fo as to rife equally afore and abaft, the furface of the water will then form another water-line parallel to the load-water-line. Again, if the fhip is lightened more, fhe will ftill rife higher; and if the fame difference ftill continues betwixt the draught of water abaft and afore, we fhall have another water line parallel to the two former;

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fo that by this means we may defcribe as many water lines as we pleafe, all parallel to one another.

In order to form an idea how thefe lines are reprefented on the different planes, let us fuppofe a fhip upon the ftocks upon a level ground, and her keel in the fame pofition, with refpect to the horizon, that it is to be in the water when loaded; we may then defcribe feveral black lines upon the fhip's bottom, which may be whitened for that purpofe, all parallel to the horizon: Thefe will all be water lines.

Now, if a fpectator be removed at any confiderable diftance from the fhip upon a line in the fame direction with the keel, all thefe black lines, which were drawn npon the fhip's bottom, parallel to the horizon, and which are actually curves, will appear to him all ftrait lines, becaufe he fees them all upon a plane formed by a fection paffing through the mid-fhip frame perpendicular to the keel. Hence the water lines will be re-prefented by ftrait lines upon the plane of the projection.

Again, if a fpectator is removed at any confiderable diftance from the fhip upon a line perpendicular to the keel, fo as to fee the whole length of the fhip at one view, the water lines will then appear to him ftrait lines, becaufe he fees them upon a plane erected perpendicular to the horizon upon the middle line of the keel. Hence the water lines will be repre-fented by ftrait lines upon the plane of elevation.

But if the fpectator be fuppofed to be placed underneath the middle of the fhip, at any confiderable depth, in a line perpendicular to the level ground, he will then, viewing the fhip's bottom upwards, difcover the curvings of all the water lines. Thefe curves are all projected upon a plane, which we muft imagine to be formed by a fection of the fhip through the load-water line, and we are now to fhew how thefe are formed.

To form the Water Lines upon the Horizontal Plane.

Let the water lines to be formed be reprefented in the plane of the projection by ftrait lines, all parallel to one another. Thefe will be re-prefented by the ftrait lines in the plane of elevation. Suppofe *q r, s t, b x*, and **T V**, all parallel to one another, and the fame diftance from the load-water line **T V** that the lines which reprefent them in the plane of the projection are from it. In order to form thefe upon the horizontal plane,

1ft, Take half the thicknefs of the poft from the plane of the projec-tion, and lay it off on the horizontal plane from A to E, and through the

<div align="right">point</div>

point E draw the line E *s* parallel to A B, five or fix feet long; lay off the fame diftance from B to F, and thro' the point F draw a line F R parallel to A B, five or fix feet long.

2d. From the points where the water lines interfect the ftern poft upon the plane of elevation, let fall perpendiculars. In like manner, let fall perpendiculars from the points where the water lines interfect the ftem.

3d. Take upon the water lines, in the plane of the projection, the feveral diftances intercepted betwixt the middle line and the curve of the midfhip frame, and lay them off from the line A B in the horizontal plane, upon the perpendicular that reprefents the midfhip frame. Take alfo from the plane of projection the feveral diftances intercepted betwixt the middle line and the curvings of the other frames, and lay them off in the horizontal plane from the line A B, upon the perpendiculars correfponding to their refpective frames, both in the fore body and after body, and curves paffing through all thefe points will give the true form of all the water lines; they end forward at the points where the perpendiculars interfect the line F R. The water lines abaft which end upon the poft in the plane of elevation, will end where the perpendiculars interfect the line E *s* upon the horizontal plane. But the 3d and 4th water lines cannot end upon the poft, by reafon of the fafhion pieces; and in order to find the points where thefe fhall end, we muft proceed in the following manner.

To find the point where the load-water line ends, let fall a perpendicular from the point *k*, where it interfects the fafhion piece on the plane of elevation, to N. Take from the plane of the projection upon the line that reprefents the load-water line, the diftance betwixt the fafhion piece and the mid-line; lay this off upon the horizontal plane from the line A B to the point N, which will end the load-water line upon the horizontal plane, from whence it may be drawn to *g*; fo *g* N will be the flat of the Tuck; and to find the point *g*, draw a line parallel to *k* N thro' the point where the line T V cuts the rabbit of the poft, which will give the point *g*. We may, after the fame manner, find the ends of the other water lines that do not go to the ftern poft for a fquare tuck.

To form the Ribbands upon the Horizontal Plane.

We obferved before, that the ribbands where thin planks nailed to all the frames from the poft to the ftem; and that when they are carried round, fo as to make fair curves, the form of all the filling timbers may be by them determined. Thefe filling timbers are to be placed betwixt

F 2   the

the frames, which were methodically laid down in the draught. We fhall here further obferve, that thefe ribbands will round two ways, one in a vertical, and one in an horizontal fenfe, occafioned by the nature of the form of the fhip's body; for they will, in carrying them about, naturally fly higher abaft and before than they are in midfhips, which gives them a vertical curve, and the narrowing of the fhip's breadth from the midfhips both ways, gives them the horizontal curve; thence they will be reprefented by different lines on all the planes.

They are reprefented upon the plane of the projection by ftreight lines, all but the breadth ribband, which is ufually reprefented by a curve; but upon the plane of elevation, and that of the horizon, they will be reprefented by curves. The reafon of thefe different appearances arifes from the different fituations in which they are fuppofed to be viewed, as was obferved in refpect of the water lines.

Now, in order to comprehend the relation betwixt thefe horizontal curves, and the lines that reprefent them upon the plane of the projection, it will be fufficient to remark, that thefe horizontal curves refult from the different lengths of the perpendiculars that are fuppofed to be drawn in the plane of the projection, from the points where the lines that reprefent the ribbands interfect the frames, to the middle line. Hence, if the lengths of thefe perpendiculars are transferred to the lines correfponding to each frame in the horizontal plane, we fhall have the points thro' which the curve that forms the ribband muft pafs.

But if thefe ribbands are to be reprefented upon a plane placed in an oblique pofition to the horizon, that is to fay, a plane that has the fame inclination to another plane erected perpendicularly upon the middle line of the keel, that the line that reprefents that ribband, has to the middle line in the plane of the projection; in that cafe, they will have a quite different form from what they have upon the plane of the horizon.

Now, to conceive the relation betwixt thefe and the lines that reprefent them upon the plane of the projection, it will be fufficient to remark, that if the feveral diftances taken upon each diagonal intercepted betwixt the middle line and the points where thefe diagonals interfect the curves of the timbers in the plane of the projection; I fay, if thefe be transferred to the lines that reprefent thofe timbers, we fhall have the points thro' which the curves that form the ribbands muft pafs.

Again, if thefe ribbands are to be reprefented upon the plane of elevation, they will have a different form from any of the former; to find which, we need only take the perpendicular diftances from the points where the diagonals interfect the curves of the timbers in the plane

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of the projection to the line that reprefents the upper fide of the keel, and transfer them to the plane of elevation, fetting them up from the upper fide of the keel upon the line correfponding to the timber, from which they were taken upon the plane of the projection. This will give us the points thro' which their curves muft pafs.

Having thus given a general defcription of thefe curves, we fhall now proceed to defcribe them upon the different planes.

To defcribe the Floor Ribband upon the Plane of Elevation.

1ft. Take the perpendicular diftance betwixt the point *a*, where the diagonal interfects frame 9, and the lower water line in the plane of the projection.

2d. Set up this diftance from the point S, where the lower water line interfects frame 9 in the plane of elevation, and we fhall have a point G, thro' which the curve muft pafs.

Now, it is plain, that we may, by repeating the fame operations, have a point in each frame, thro' which the curve of the ribband muft pafs upon the plane of elevation. After the fame manner are all the other ribbands formed.

To defcribe the Ribbands upon the Horizontal Plane.

The breadth ribband is formed by transferring the lengths of all the perpendiculars that are fuppofed to be drawn from the points where the curve that reprefents this ribband interfects the timbers, to the middle line in the plane of the projection: This curve, in the plane of the projection, is drawn from the breadth in midfhips to the extremity of the wing tranfom.

1ft. Lay off the length of the wing tranfom upon the perpendicular N L.

2d. Take the length of the perpendicular drawn, from the point where the curve that reprefents the breadth interfects frame 9, to the mid-line in the plane of the projection; lay off this from the line A B upon the perpendicular reprefenting frame 9 in the horizontal plane, to the point S, which will be one of the points thro' which the curve of the ribband muft pafs. We may proceed in the fame manner to find points upon all the perpendiculars, both afore and abaft, fo fhall the curve L, S, Q, 1, be the form of the breadth ribband. But to compleat this ribband, the round aft of the wing tranfom muft be fet off.

To

To form the Oblique or Cant Ribbands.

We obſerved before, that theſe ribbands could not be formed either upon the horizontal plane or that of elevation, upon which account they were feldom drawn, becauſe each muſt be drawn upon a ſeparate plane. However, thoſe who incline to draw them may uſe the following method :

Let it then be required to form the firſt ribband repreſented in the plane of the projection, by the diagonal H G.

1ſt.   Produce line H G to the point *p* in the middle line upon the plane of the projection.

2d.   Take the height of the point *p* above the line that repreſents the upper ſide of the keel in midſhips, in the plane of the projection ; ſet up this from the ſame line in the plane of elevation, on a perpendicular, upon the poſt, from which point let fall a perpendicular to the point F in the line C D, and produce all the perpendiculars that repreſent the frames to the line C D; ſo F Q will be the axis of the ribband from the poſt to the midſhips.

3d.   Take upon the plane of the projection, in the line H *p*, the diſtance *p* G, which ſet off upon the perpendicular from the point F to *f*.

4th.   Take the diſtance on the diagonal from the point *p* in the middle line to its interſection with the frame 9.   Set off this from the line C D upon the perpendicular correſponding to frame 9; this will give us a point thro' which the curve muſt paſs.   Do the ſame for all the other frames to the midſhip.

In like manner the curve for the fore part of the ribband is formed from the interſections of the diagonal 4, 5, with the curves of the frames in the plane of the projection ; but it is evident, this is a different plane from that of the line H *p*; therefore we muſt have a different axis for the curve of the fore part of the ribband.   In order to which, take from the plane of the projection the diagonal 4, 5; ſet off this from the point O to Z, and draw the line Z X parallel to C D.   We muſt likewiſe take the height of the point 4 in the plane of the projection, and ſet it up on the ſtem ; from which point letting fall a perpendicular to the line Z X, we ſhall limit the fore end of the ribband.   The points thro' which the curve muſt paſs will be found the ſame manner as thoſe for the after-body.

The builders make uſe of the cant ribbands to find the bevellings of the timbers ; for we muſt repreſent each frame as one intire piece of circular timber, and being all faſtened to the keel they form the ſide of the ſhip.   They are ſquare upon the upper ſide of the keel ; but becauſe

both

both the outfide and infide of the fhip's fides, length-ways, form curves, it is plain, that the fections of any of the frames, the midfhip only excepted, will produce a furface in the form of a lozenge or rhombus; the angles which are formed by thefe fections are what are called the bevellings of the timbers.

The fhip-wrights take thefe angles mechanically by an inftrument called a bevel; thus they draw, upon the plane of the ribband, a line parallel to that which reprefents the frame, and diftant from it the whole breadth of the timber; and applying the ftock of the bevel to the line that reprefents the frame, and the tongue to the ribband, they have the quantity of the angle which forms the bevelling of the timer at that place.

It is plain the angle b, a, c, which points to the midfhip frame, will be obtufe, whereas the angle b, a, d, which points to the poft, will be acute.

Now, as every timber has two planes, that which points to the midfhips will have what they call a ftanding bevelling, and that which points either to the poft or ftem will be under bevelling.

We fhall fhew in another place how the modern builders, by putting the frames in an oblique pofition to the keel afore and abaft, leffen the bevellings.

C H A P. VI.

Another Method of laying down the Horizontal Plane, and the Plane of Projection.

THOSE who are well verfed in the art of drawing have taken a method quite different from any of thofe we have defcribed, which fhall be the fubject of this chapter.

After forming the plane of elevation, and drawing all the perpendiculars for the frames, as before, the following method muft be obferved:

I.

To lay down the Breadth Ribband on the Horizontal Plane.

The extremities of it on the ftem and poft, and the point thro' which it is to pafs on the midfhip frame are found as directed in the preceeding chapter. It remains now to find the points in the balance frames, thro' which it is to pafs.

To find the point in the fore balance frame take $\frac{188}{200}$ parts of half the

<div align="right">main</div>

main breadth, which fet off on the line that reprefents that frame in the horizontal plane from K to L.

To find the point in the balance frame abaft, take $\frac{2\,1\,4}{1\,0\,0}$ parts of the half of the main breadth from M to N. It will be neceffary to have another point in the fore body, thro' which the curve muft pafs; for which purpofe ufe the following method:

Divide the fpace contained betwixt the line that reprefents the balance frame afore and the rabbit of the ftem, into two equal parts, and draw the line *o p*, on which fet off the 160th part of the main breadth, which will give the point *p*, thro' which the curve is to pafs. It muft be obferved, that the proportions for finding thefe points may be varied according to the form we propofe to give to the ribband. After the points H, N, Q, L, *p*, *s* are thus fet off, we may defcribe the curve either by moulds or penning battens.

II.
To lay down the Floor Ribband on the Horizontal Plane.

1ft. The height of this ribband muft be determined both upon the poft and ftem, from which points letting fall perpendiculars, we fhall have the extremities of it on the horizontal plane, obferving to allow for the rabbit.

2d. Take half the length of the midfhip floor timber, and fet off on the line that reprefents the midfhip frame on the horizontal plane from *a* to *s*, which will be the point thro' which the curve muft pafs.

3d. Take $\frac{1\,4\,3}{1\,0\,0}$ of the line *a s*, the breadth at the midfhip frame, and fet it off on the balance timber afore, from K to T, and fet off $\frac{1\,4\,8}{1\,0\,0}$ of the fame line, upon the balance timber abaft to V, and draw the curve thro' the points G, V, S, T, R.

III.
To lay down the after Balance Timber upon the Plane of Projection.

1ft. Produce the line which reprefents it on the horizontal plane to the fheer rail, on the plane of elevation, and take the diftance upon this line betwixt the upper fide of the keel, and the lower edge of the fecond wale, which here reprefents the breadth ribband; fet up this from A to C on the plane of the projection, from which point draw the line C D, perpendicular to the middle line. *(Plate II. Fig.* 1, 2, 3.)

2d. Take the line M N in the horizontal plane, and fet off from D to E, which will give one point, through which the curve of the timber muft pafs.

3d. Take

3d, Take the height of the floor ribband, in the plane of elevation, and set it up on the plane of the projection to G; from the point H, at the end of the floor timber, draw the line H G, which will reprefent the floor ribband on the plane of the projection. (*Plate* II. *Fig.* 1. 2. 3.)

4th, Take the diftance M V, in the horizontal plane, with a pair of compaffes, and move the compaffes with one foot, in the middle line, and the other in a line perpendicular to it, till it interfect the diagonal in the point L, thro' which the curve of the frame muft pafs. To thofe who are acquainted with drawing, the three points E, L, F, will be fufficient to form the timber; they who incline to have another point may divide the line A C into two equal parts by a perpendicular M K, drawn to the middle line, from which fetting off $\frac{131}{100}$ of the line M K, we fhall have another point thro' which the curve muft pafs.

IV.

To lay down the ninth Frame abaft on the Plane of the Projection.

Take the height of the breadth ribband at this frame, in the plane of elevation, and fet it up on the plane of the projection from F to O, and draw the line O P perpendicular to the middle line. (*Plate* II. *Fig.* 1. 2. 3.)

2d, Take the diftance X S in the horizontal plane, and fet off from O to P, which will be the point thro' which the curve muft pafs.

3d, Take the diftance X Z in the horizontal plane, which fet off from the middle line, to interfect the diagonal that reprefents the floor ribband, in the plane of projection in Q, obferving to keep the compaffes as before directed.

4th, Divide the line K O in two equal parts, and draw the line R S perpendicular to the middle line, ou which fet off $\frac{154}{100}$ of the line P O, from R to S, and draw the curve thro' the points P, S, Q, F, which will be the form of the ninth frame.

V.

To lay down the intermediate Ribbands abaft on the Plane of the Projection.

1ft, Take the diftance betwixt the upper fide of the keel and the breadth, upon the line that reprefents the midfhip frame, in the plane of elevation, and fet it up from A to T, and from B to T, in the plane of the projection, fo fhall the line T T give the height of the breadth ribband in midfhips.

2d, Divide the curve H M T into as many equal parts as there are to be intermediate Ribbands; divide alfo the curve of the ninth frame Q S P into the fame number, and, thro' thefe divifions, draw the diagonals which will reprefent the ribbands as in the plate.

G   VI. To

VI.

To lay down the firft intermediate Ribband upon the Horizontal Plane.

1ft, Take the neareft diftance of the point V (which is the extremity of the diagonal in the plane of the projection) to the middle line O F, fet off this on the line which reprefents the midfhip frame in the horizontal plane, which will give the point thro' which the curve muft pafs at that place. After the fame manner we may find the points in the lines that reprefent the balance and ninth frames in the horizontal plane.

2d, Take F Z, the height of the ribband upon the rabbit of the poft, in the plane of the projection, and fet it up on a perpendicular, to the point *k*, on the line that reprefents the rabbit of the poft in the plane of elevation; take the neareft diftance of the point *k* to the perpendicular of the poft, which fet off from F to *e*, and this will be the end of the ribband: So a curve paffing thro' the points *e*, *d*, *c*, *b*, will be the form of the ribband.

VII.

To lay down the Wing Tranfom upon the Plane of the Projection, and on the Horizontal Plane.

1ft, Take the height of the upper fide of the wing tranfom (including the round up) in the plane of elevation, and fet it up in the plane of the projection to the point *e*.

2d, Take the height in the plane of elevation, without regarding the round up, and fet off from F to *f*, and draw the line *f g* perpendicular to the middle line, on which fet off the length of the tranfom from *f* to *g*, this is equal to the line G H in the horizontal plane. The curve *g e* reprefents the upper fide of the wing tranfom.

The round aft of the tranfom is reprefented upon the horizontal plane by the curve L *k e*; H L is the fquare end of it.

VIII.

To lay down all the Frames in the after Body.

All thefe are laid down in the fame manner as the ninth and balance frames before defcribed, that is, by taking the half breadth of the ribbands at each frame in the horizontal plane, and fetting them off from the middle line in the plane of the projection to interfect the diagonal correfponding to the ribband, as directed in forming the balance frame, by this means we fhall divide each into as many points as there are frames: The curves drawn thro' thefe points will give the form of all the frames in the after body.

IX. *To*

<center>IX.</center>

To lay down the Position of the Fashion Piece on the Horizontal Plane.

Let fall the perpendicular G H, from the end of the wing transom, and draw the line H *l*, which will represent the plane of the fashion piece upon the horizontal plane, observing to make the angle G H *l*, about 25 degrees.

<center>X.</center>

To form the Fashion Piece in the same manner it is to be, when put into its proper place in the Ship.

The fashion piece laid down in the plane of the projection, regards that frame as it would appear when viewed from abaft; but as the fashion pieces on each side are not in one plane, as all the rest of the frames are, we shall be much deceived, if we imagine that the fashion piece laid down in the plain of projection, will give the true form of that which is to be put in the ship. We must therefore lay it down upon another plane, and, to avoid confusion, we shall separate it from the plane of projection.

Note, The fashion peice, mention'd by our author, described in the plane of the projection, is that betwixt the ninth frame, and the curve f q o G, *which represents the fashion piece of a square tuck; it is formed in the same manner as the rest of the frames, by tranferring the lines* n m, p o, *&c. in the horizontal plane, to the plane of projection, to interfect the diagonals coresponding to these ribbands in the points* i, l, *&c :*

1st, Draw the line *f* G, to represent the middle line of the plane of projection. (*Fig.* 4.)

2d, Draw the line *f g* perpendicular to G *f*, to represent the wing transom.

3d, From *i*, the point where the fashion piece interfects the floor ribband in the plane of the projection, take the nearest distance to the line *f g*, which represents the wing transom, and set off this distance in *Fig.* 4. from *f* to *h*, and draw the line *h l* parallel to *f g*.

4th, From the point *l*, where the fashion piece interfects the first intermediate diagonal, in the plane of projection, take the nearest distance to the line *f g*, set it off from *f* to *k*, in *Fig.* 4, and draw the line *k m*, parallel to *f g*.

5th, In like manner, the points where the fashion piece interfects the second and third diagonals in the plane of projection, are to be transferr'd to the points *q* and *n*, *Fig.* 4, and the lines *p q*, *n o*, drawn parallel to *f g*.

<center>G 2</center>	6th,

6th, To find the points through which the curve muſt paſs: Take the line *l* H, which repreſents the poſition of the faſhion piece upon the horizontal plane; lay this off from *f* to *g*: Again, take the diſtance *l y* in the horizontal plane; which lay off from *q* to *p*, in like manner ſet off the diſtance *l z*, from *n* to *o*; and the diſtance *l p* from *k* to *m*, and laſtly, the diſtance *l n*, from *h* to *l*; ſo a curve drawn through the points *g*, *p*, *o*, *m*, *l*, will give the true form of the faſhion piece.

XI.

To lay down the Faſhion Piece upon the Plane of Elevation.

1ſt, Take the ſeveral heights above the keel, of the points where the faſhion piece interſects the diagonals in the plane of projection, and transfer them to the lines *o*, *p*, *q*, *z*, *y*, in the plane of elevation, drawn parallel to the keel, and the ſame height above it, that their correſponding points are in the plane of projection.

2d, Take the neareſt diſtance of the point *n*, in the horizontal plane, to the line C F, the perpendicular from the head of the poſt, ſet off this from the ſame line in the plane of elevation upon the line *p*; which will be the point through which the curve muſt paſs.

3d, In like manner the points *z*, *y*, muſt be transferr'd from the horizontal plane, to the plane of elevation in the points *z*, *y*, a curve paſſing through theſe points will be the projection of the faſhion piece on the plane of elevation.

We ſhall here remark, that ſome builders to avoid giving a great bevelling to the timbers, and likewiſe that they may not require ſuch compaſs timber, do change the direction of all the frames in the fore-body before that of the loof; that is, the lines that repreſent them in the horizontal plane make an acute angle with the line that repreſents the keel; theſe are called cant timbers, and may be formed in the ſame manner as the faſhion piece, which we have now deſcribed. Tho' ſeveral builders form all the frames perpendicular to the keel, to have the floor timbers in one piece, which will be much ſtronger that when in two pieces, and this will inevitably be the caſe when the timbers are canted.

We might here ſhew how to lay down the top timbers, but as that part under water is the moſt material, we ſhall proceed to form the timbers afore.

XII.

To lay down the Frames for the Fore-body.

The balance and the eighth frame muſt firſt be formed in the ſame manner as the balance and ninth frame abaft: In order to which the curve

that

that reprefents the breadth ribband muft be laid down in the plane of the projection afore.   The diagonal, which reprefents the floor ribband, muft likewife be laid down in the plane of the projection, for which purpofe we muft take the height of the ribband above the keel, upon the rabbit of the ftem, and fet it upon the line that reprefents the rabbit of the poft in the plane of the projection, to the point 4; from which draw a line to the floor head, fo 4 5 will reprefent the floor ribband.

XIII.

To fpace the Diagonals that reprefent the Ribbands afore, in the Plane of the Projection.

1ft. As the points of their interfection at the midfhip frame are the fame afore that they are abaft, we need only transfer them from abaft to the fore body.

2d. Take the height of the breadth ribband upon the ftem, in the plane of elevation, and fet it up from F to 17 in the plane of projection.

3d. Divide the diftance betwixt 4 and 17 into four equal parts, which will give the points in the plane of projection, where the immediate diagonals end on the ftem.

After the diagonals are drawn in the plane of the projection, the ribbands may be laid down in the horizontal plane, and from thence all the other frames may be laid down in the plane of projection, in the very fame manner that the horizontal ribbands and the frames for the afterbody were laid down.

CHAP.

CHAP. VII.

General Remarks on Ship Building.

ALL the rules we have hitherto laid down, collected from the principal dimensions of ships built by the most eminent masters, should only be so far regarded as they may assist the artist in forming the body in such a manner as to produce effects answerable to the service for which the vessel is designed.

In order to qualify a builder for such an undertaking, it is necessary he should understand the nature of fluids, and of such bodies as will float in the water; when he has made himself acquainted with these, I would recommend him to M. *Bouguer's* treatise on ship-building.

The principal Qualities belonging to Ships.

1st. To be able to carry a good sail, not only because, in forming the body, the water lines are all supposed to be described when a ship is upright in the water, but likewise for doubling a cape, or getting off a lee shore, which will be impossible to be done when a ship lies over in the water, this will likewise render her lower tier, if not all her guns, useless.

2d. A ship should steer well, and feel the least motion of the helm.

3d. A ship should carry her lower tier of guns four feet and a half, or five feet out of the water, otherwise a great ship, that cannot open her ports upon a wind, but in smooth water, may be taken by a small one, that can make use of her guns, or she must bare away before the wind, to have the use of her guns; on which account it will be proper to raise the ports higher before than in midships, because the fore part of the ship is often pressed into the water by carrying sail.

4th. A ship should be duly poised, so as not to dive or pitch hard, but go smooth and easy through the water, rising to the sea when it runs high, and the ship under her courses, or lying to under a mainsail, otherwise she will be in danger of carrying away her masts.

5th. A ship should sail well before the wind, large, but chiefly close hawled, keep a good wind, not fall off to the leeward.

Now the great difficulty consists in uniting so many different qualities in one ship, which seems indeed to be impossible; the whole art therefore consists in forming the body in such a manner, that none of these qualities shall be entirely destroyed, and in giving the preference to that which is most required in the particular service for which the vessel is built; in order to
<div align="right">which</div>

which, it will be neceffary to know, at leaft nearly, what form will give a veffel one of thefe qualities, confidered abftractly from the reft.

To make a Ship carry a good Sail.

A flat floor timber, and fomewhat long, or the lower futtock pretty round, a ftreight upper futtock, the top timber to throw the breadth out aloft; at any rate to carry her main breadth as high as the lower deck: Now, if the rigging be well adapted to fuch a body, and the upper works lightened as much as poffible, fo that they all concur to lower the center of gravity, there will be no room to doubt of her carrying a good fail.

To make a Ship steer well, and quickly answer the Helm.

If the fafhion pieces be well formed, and the tuck carried pretty high; the midfhip frame carried pretty forward; a confiderable difference of the draught of water abaft more than afore; a great rake forward, and none abaft; a fnug quarter-deck and forecaftle, all thefe will make a fhip fteer well; but to make her feel the leaft motion of her helm, it will be neceffary to regard her mafts. There is one thing not to be forgot, that a fhip which goes well will certainly fteer well.

To make a Ship carry her Guns well out of the Water.

It is plain, that a long floor timber, and not of a great rifing; a very full midfhip frame, and low tuck with light upper works, will make a fhip carry her guns high.

To make a Ship go smoothly through the Water without pitching hard.

A long keel, a long floor, not to rife too high afore and abaft, the area or fpace contained in the fore body, duly proportioned to that of the after body, according to the refpective weights they are to carry; all thefe are neceffary to make a fhip go fmoothly through the water.

To make a Ship keep a good Wind.

A good length by the keel, not too broad, but pretty deep in the hold, which will occafion her to have a fhort floor timber, and great rifing.

As fuch a fhip will meet with great refiftance in the water, going over the broad-fide, and little when going a-head, fhe will not fall much to the leeward.

Now, fome builders imagine that it is not poffible to make a fhip carry her guns well, carry a good fail, and to be a prime failer, becaufe it

would

would require a very full bottom to gain the first two qualities, whereas a sharp ship will best answer for the latter; but when it is considered that a full ship will carry a great deal more sail than a sharp one, a good artist may so form the body as to have all these three good qualities, and likewise steer well, for which purpose I would recommend somewhat in length more than has been formerly practised.

After what has been said upon this head, I believe it will not be thought impossible to unite all these different qualities in one ship, so that all of them may be discerned in some degree of eminence; but when it happens otherwise, the fault must be owing to the builder, who has not applied himself to study the fundamental rules and principles of his art.

Excepting some antient builders, who were happily born with a natural genius, and our moderns, who being instructed in the principles of the mathematics, have truly laboured very hard to make a progress in the art of shipbuilding, one may, without violating the truth, affirm that the greatest part satisfy themselves with copying such ships as they esteem good sailers, and it is these servile mechanick methods, which, to the great reproach of the art, are but too common, that have produced all these pretended rules of proportion, all these methods of describing the mid-ship frame, and forming the rest of the timbers, which every builder endeavours if possible to conceal, and keep wholly in his own family.

How low and mean is this? it is as if a great architect should endeavour to conceal the proportions of the different orders of architecture; whereas they are published every where, and so well known that many can raise a very beautiful porch or triumphal arch; but tho' the methods of describing the midship frame, and forming the rest of the timbers, be known to most apprentices, yet we have but few good master builders: This requires more than those mechanick rules; they should at least have such a knowledge of the mathematicks, physicks, mechanicks, of the nature of solids and fluids, as to be able to discover what figure would procure some good quality, without hazarding or putting a bad one in its place.

Let us suppose one to have a collection of draughts of a vast number of ships, and whose good and bad qualities have been remarked with all possible exactness, such a valuable treasure would be of great service to a person who could calculate precisely by the draughts where the fault lay, and how it might be rectified. For instance, suppose a ship sails well, but carries her guns too low, a builder who is not acquainted with these principles would raise her deck, in consequence of which she would not sail well; whereas, one that could exactly calculate how much the resistance of the fluid is diminished upon the prow, would take great care

to

.to add no more to any of the other parts than he could find by an exact calculation might be done without augmenting the resistance in the fluids.

M. *Bouguer* has published several useful problems for making these calculations, to which we refer the reader, and only explain what regards the height of the gun deck, and the resistance of the fluid, in one example of a 70 gun ship.

C H A P.   VIII.

To know by the Draught how high a Ship will carry her Guns out of the Water.

THIS is only to know if, when a ship is loaded with all her ammunitions and provisions on board, and ready to sail, her seat in the water will then agree exactly with the load water line in the draught.

It may be demonstrated by several experiments, that any floating body of whatsoever figure will just sink so far in the water as to displace a bulk of water of equal weight with itself.

Hence it will be necessary, first to find a method of calculating the exact weight of a ship ready equipt for sea, and secondly, to know the exact weight of the water the ship displaces, when loaded to the water line in the draught.

In order to the first, the exact weight of all the timber, iron, lead, masts, sails, rigging, and in short of all the materials, men, provisions, and every thing else on board the ship must be known.

It must be confessed that this is a very laborious task, yet the zeal of our modern builders has surmounted all these difficulties, and got the exact weight of a ship of each class, with all its furniture, and six months provisions on board. It will be sufficient for our purpose to give the particulars, of the two following, one of 30 and another of 50 guns, both ready equipt for sea, with six months provisions on board.

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An Estimate of the Weight of the RENOMEE Frigate of Thirty Guns, with Six Months Provisions.

WEIGHT of the HULL.

	Cubic feet	Under water Pounds	Above water Pounds.	Total Tons	Total Pounds
Oak timb- { under w. at 72 *lb.* per f.	5640	406080		299	800
ber { above w. at 66 *lb.*	2920		192720		
Fir at 50 *lb.* per foot { under water	600	30000		29	000
{ above water	560		28000		
Carved work ———			2200	1	200
Iron knees and standards		4200	7010	5	1210
Bolts, rudder irons, chain plates, nails		11650	6558	9	208
Lead for the hause holes & scuppers		250	430	0	680
Locks ————			170	0	170
Oakum ———		1200	1830	1	1030
Pitch and Tar ———			650	0	650
Paint ———————			440	0	440
In the Cook room ———			8000	4	000
Total		453380	248008	350	1388

WEIGHT of the FURNITURE.

	Under W. Pounds.	Abov W Pounds.	Total Tons	Total Pds
Masts compleat set and spare	3000	37000	20	00
Blocks ———	1000	5444	2	444
Pumps ————	1734	670	1	404
Cables and Hawsers	24444		12	444
Sails and their Cases	4222	3778	4	000
Anchors and their Stocks	2811	6944	4	1555
Cordage for the rigging		17282	8	1282
The master's Stores	3333		1	1333
Boats ——— ———		6666	3	666
Total	40344	75784	58	128

WEIGHT of the PROVISIONS, &c.

	Under water. Pounds.	Above water Pounds.	Total Tons	Total Pounds
Provisions for 6 months for 200 men with all their equipage	245420		122	1420
Water for two months and a half	100000		50	000
Casks ———	32800		16	800
The Captain's table	15000	5000	10	000
Total	393220	5000	199	220

WEIGHT of the OFFICERS STORES.

	Under water Pounds.	Above water Pounds.	Total Tons	Pds
The Carpenter's Stores	3000	1000	2	00
The Caulker's Stores	1000		0	1000
The Surgeon's Effects	2400		1	400
The Pilot's Effects	740	360	0	1100
The Chaplain's Effects		100	0	100
	7140	1460	4	600

WEIGHT of the GUNS and AMMUNITION.

	Under water Pounds.	Above water Pounds.	Total Tons	Pds
Iron Guns		60300	30	300
Carriages fitted		14000	7	00
Balls round and cross bar	11570	2430	7	00
Balls of one pound	600		0	600
Powder and Powder Barrels	7108	112	3	1220
Implements for the powder	1368	132	0	1500
Crows, Handspikes, Gunners Utensils, and Stores	3200	1500	2	700
Musquets, Cutlasses, and Pole Axes		900	0	900
	23846	79374	51	1420

WEIGHT of the MEN and their EQUIPAGE.

	Under water Pounds.	Above water Pounds.	Total Tons	Pounds
8 principal Officers and their Effects		4000	2	00
200 Men and their Effects		40000	20	00
Total		44000	22	00
BALLAST	200000		100	00

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RECAPI

RECAPITULATION.

	Under water Pounds.	Above water Pounds.	Total Tons	Total Pounds
The Hull	453380	248008	350	1388
The Furniture	40344	75784	58	128
The Provisions	393220	5000	199	220
Officers Stores	7140	1460	4	600
Guns and Ammunition	23846	79374	51	1220
Weight of the Men		44000	22	00
Ballast	200000		100	00
Total	1117930	453626	785	1556

An Estimate of the Weight of a Frigate of Fifty Guns, with Six Months Provisions.

	Under water Pounds.	Above water Pounds.	Total Tons	Total Pounds
The Hull	774270	769134	771	1404
The Furniture	98237	163184	130	1421
Ballast	300000		150	000
Guns and Ammunition	679400	199320	133	1280
Provisions	659400	8000	333	1400
Stores	9800	2800	6	600
Men and their Equipage		77000	38	1000
Total	1909667	1219458	1564	1105

But as all ships of the same class are pretty near the same dimensions, and have the same number of guns, &c. we may have the exact weight of each only by examining the draught of water, and computing the weight of that column of water which is displaced by the ship.

Now if the *Intrepide* weighs 2718 tuns, she must sink so far into the water till she has displaced a column of water containing $73459 \frac{17}{74}$ cubick feet, for a cubick foot of salt water being supposed to weigh 74 lb. the $73459 \frac{17}{74}$ will weigh 5436000 lb. or 2718 tuns, or if she displaces $73459 \frac{17}{74}$ cubick feet of salt water, we may thence conclude that she weighs 2718 tuns.

In like manner, if the weight of the ship which is to be laid down in

the

the draught be known; as, for inftance, that if a fhip of 78 guns, is 2350 tons, we may with certainty know if the water line in the draught be properly placed, only by reducing the bottom into cubick feet.

The antient builders were unacquainted with the manner of performing this, but our moderns make an exact calculation of the contents of the bottom before they begin to build, whereby they will be fure to keep the lower tier of guns well out of the water.

If a fhip's body were any regular figure, the folid contents of it could eafily be found geometrically, but as the cafe is quite otherwife, we muft be fatisfied with dividing it into feveral parts, of which we may have a great number, and they will thereby become fo fmall, that they may, without any fenfible error, be efteemed as regular figures, limited by ftreight lines, tho' fome of them are actually curves.

In the draught of the 70 gun fhip which we have laid down, the bottom is divided on the plain of elevation into feveral parts, in a vertical way, by the lines that reprefent the frames; and in an horizontal way by the water lines; fo that the whole may be faid to be divided into fo many parallelopipedons, A, B, C, D, or *a, b, c, d*, contained betwixt the two frames 6 and 7, and limited on the fide A B by a plain fuppofed to be erected vertically upon the keel, and on the other fide by the round of the outfide of the fhip, at the height of the breadth water line, or *a c.* Now it is very plain that the area of the furface, which limits the lower part of this folid, is lefs than the area of the furface, which limits the upper part: But if we increafe the water lines and frames, we may find the folid contents to a fufficient exactnefs for our purpofe.

Now, in order to find the area of the upper furface A B C D, let A C be 16 feet 11 inches, and B D 13 feet 6 inches; add thefe two, the fum is 30 feet 5 inches, the half of which is 15 feet 2 inches and a half, and this fum multiplied by A B, which fuppofe 8 feet, the diftance betwixt the frames, the product is 121 feet 8 inches, the area of the upper furface of the parallelopipedon.

The area of the lower furface of the parallelopipedon may be found after the fame manner, which fuppofe 97 feet 4 inches. Now, if thefe two areas be added together, their fum will be 219 feet, the half of which is 109 feet 6 inches for the mean area, and this multiplied by *a b*, the diftance betwixt the water lines, which fuppofe 4 feet 4 inches, produces 474 feet 6 inches cubick.

By the fame procefs we may find the folid contents of the other parallopipeds, and adding them together, and doubling that fum, we fhall have

the

the folid content of the whole bottom of the ship in cubick feet to a sufficient degree of exactnefs.

I made ufe of this method before M. *Bouguer*'s treatife was publifhed, where there is one which is more convenient and expeditious, for, inftead of finding the area of every fingle furface contained betwixt the frames upon the fection of a water line, he finds by one operation the area of the whole furface formed by the horizontal fection or water line, except that part intercepted betwixt the aftermoft frame and the poft, and the part contained betwixt the foremoft frame and the ftem, which, upon account of the rake muft be meafured feperately, as alfo all that lies betwixt the upperfide of the keel and the firft water line. His method is as follows :

Take the lengths of all the lines that reprefent the frames on the horizontal plane, add all thefe together, excepting the foremoft and aftermoft, of which take only one half of each, fo if it were required to find the area of the furface formed by a horizontal fection in the plane of the load water line, it will be $\frac{1}{2}$ ZZ+BD+AC+IH+LK, *&c.* +KS×AB, fuppofing AB to be the diftance betwixt the frames equally fpaced betwixt ZZ and NO,

To demonftrate this, let it be confidered by what operation the two trapezia ABDC and HIAC are meafured. We obferve in the proceeding article that this was performed by adding the length of the lines BD and AC together, and then taking half that fum ; the length of the lines AC and HI, muft likewife be added together, and the half of that fum taken ; now it is evident that it will be the fame thing to take half the line BD, and half the line HI, and the whole line AC, and add all thefe three together, becaufe the line AC, is common to both the trapezia.

After the areas of all the water lines are thus found, the folid content of the fpace contained betwixt the water lines may be had by multiplying the area by the diftance between the water lines : But, becaufe the areas of the two furfaces which limits this part are unequal, a mean area muft be found ; this is half the fum of the two areas, fo that all that is now to be done, is to add the areas of the water lines into one fum, excepting that of the upermoft and lowermoft, of which only one half of each muft be taken, and if this fum is multiplied by the diftance betwixt the water lines, the product will give half the folid content of the bottom, obferving that the water lines in the plain of elevation be equally diftant from one another.

The application of this method in finding the cubick feet contained in a 70 gun fhip laid down in the draught.

The

The forepart is divided into eight, and the after into nine equal parts, besides that betwixt the aftermoft timber and the poft, and that betwixt the foremoft timber and the ftem.

The bottom is likewife divided into four equal parts by water lines drawn parallel to the load water line, all which are formed upon the horizontal plane; for it will be very ufeful to know the folid content of each particular part contained betwixt the water lines, alfo to diftinguifh that of the fore body from the after body, whereby we may be enabled to know if the weight be duly poifed. We fhall confider all this in the following calculation.

Note, there muft be four inches added to each line that reprefents the frames in the horizontal plane for the thicknefs of the plank, that being nearly a mean betwixt the thicknefs of the plank next the wale, and that next the keel.

The Area of the Upper Water Line abaft.

The breadth of the furface at the load water line, upon the midfhip frame *a* Q is 21 feet 2 inches,

		feet.	inch.
one half is		10	7
Breadth at 1ft Frame		21	2
2d Frame		20	11
3d Frame		20	9
4th Frame		20	5
5th Frame		19	11
6th Frame		18	11
7th Frame		17	4
8th Frame		15	7

The 9th Frame X S is 12 feet 9 inches, one half of which is   6   4½

Total   171   11½

which total doubled is 343 feet 11 inches, and multiplied by 8, the diftance betwixt the frames, is the whole area of the water line, from the midfhip to the after frame, in cubick feet   2751   4

To this muft be added the area of the trapezium X S L *e*

Now half of the lines X S and L *e* is   10 feet 0 inches

Diftance betwixt them is   9   9

Product is   97   6

which being doubled is   195   0

The whole area in cubick feet   2946   4

By ufing the fame procefs, we may find the areas of all the other water lines; and adding all thefe areas together, excepting that of the firft and fifth, of which taking only one half, multiply this fum by 4 feet 5 inches,
which

which is the diftance betwixt them, we fhall have the area in cubick feet of that part of the fhip abaft the midfhip frame, contained betwixt the lower water line, and load water line.

	feet	inch.	l.	p.
Half of the area of the load water line	1473	2	0	0
Whole area of the 4th water line	2516	1	4	0
Whole area of the 3d water line	2052	0	4	0
Whole area of the 2d water line	1452	10	7	6
Half the area of the 1ft water line	144	3	2	0
Total	7638	5	5	6
Multiplied by the diftance betwixt the water lines	4	5	0	0
Product in cubick feet betwixt the lower and load water line	33736	6	1	3 6
Betwixt the lower water line and keel	333	6	3	0 0
Keel and poft	101	8	0	0 0
Cubick ft. abaft the midfhip frame under water, when loaded	34171	8	4	3 6
Cubick ft. before the midfhip frame under water, when load.	28928	6	1	0 0
Total cubick feet under water	63100	2	5	3 6
Multiply by the weight of a cubick foot of falt water			pounds	74

	pounds.	tons.	lb.
Weight of the whole fhip, with all her furniture, provifions, &c.	4661498	2334	1498

We have omitted the operation for the fore part, becaufe it is performed exactly by the fame method with the after part.

It muft be obferved, that in finding the cubick feet of that part contained betwixt the lower water line and upper fide of the keel, we muft take the heights of all the frames intercepted betwixt thefe two lines, and divide their fum by the number of frames abaft the midfhip, the quotient will be 1 foot 9 inches 9 lines.

	Feet	In.	Lines
The area of the lower water line is	288	6	4
The area of the upper fide of the keel	79	6	0
Total	368	0	4
One half is	184	0	2
Area of that part contained betwixt the lower water line and keel	333	6	3

The ufe of the preceding calculation is to know if the load water line upon the draught be properly placed.

It has been found that a fhip of 70 guns, with every thing on board, fhould weigh nearly 2350 tons, which is only 15 tons 1297 pound more than what is found by calculating from the load water line in the draught, this difference would occafion the fhip not to draw above one inch more

wat

y   z

N

P

x

d   e

T

a   c

u

b   d

x

s

f

t

l

h

r

q

Fig 2

6   7   r 8

I

o

G

M

A   o   B   z

B
F

3 H   6 M   II

5

8

27

2

D

14

C   p   p   X

Fig. 5.

Fig. 7.

Fig. 8.
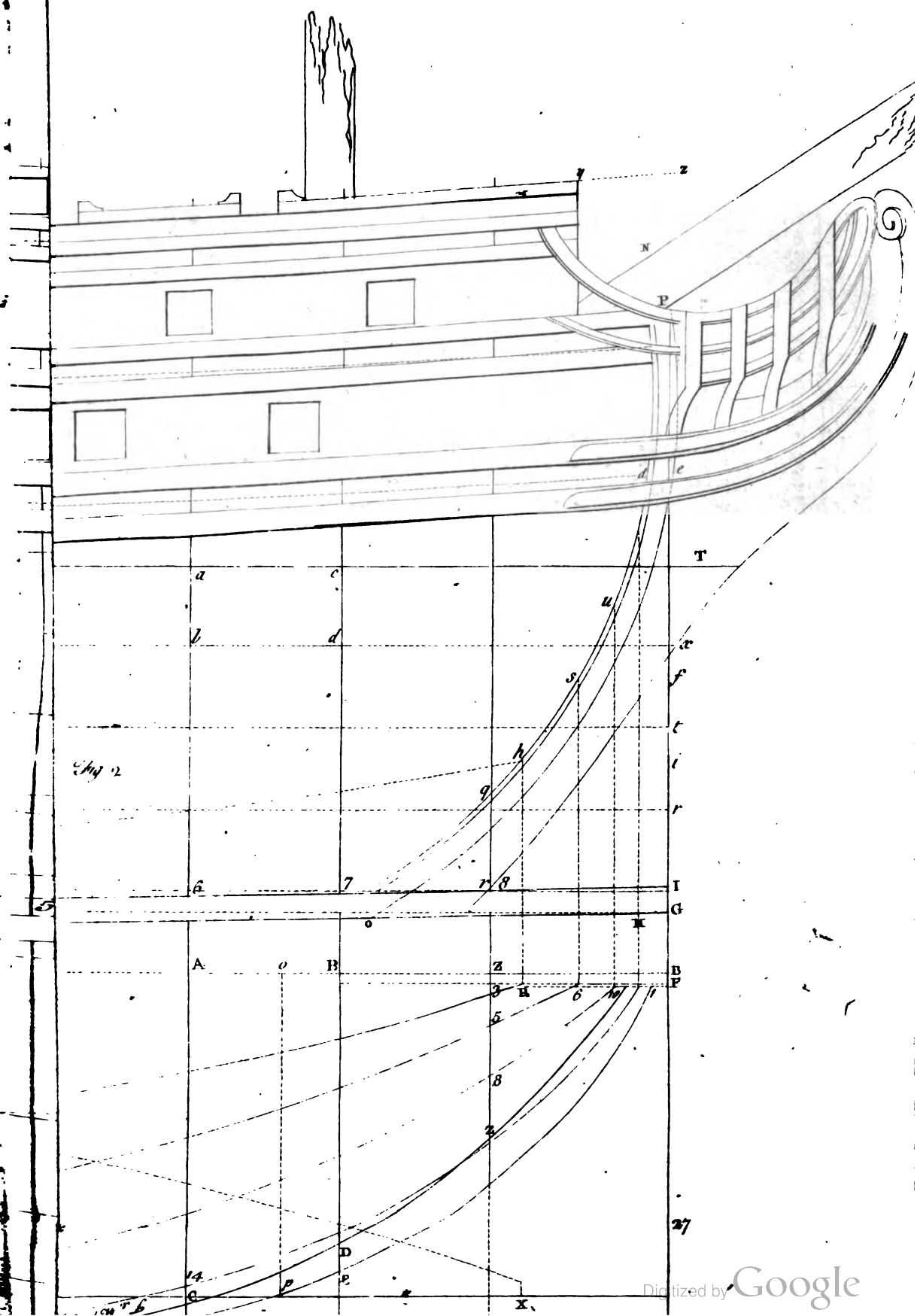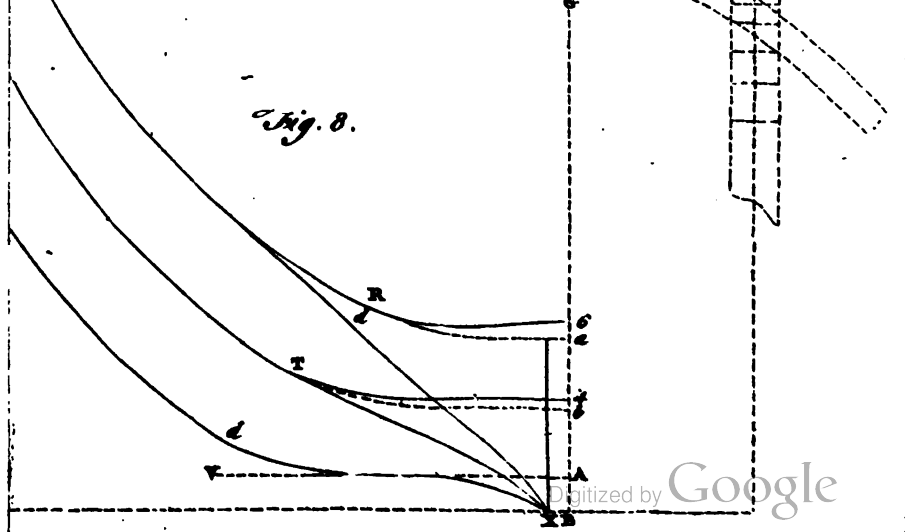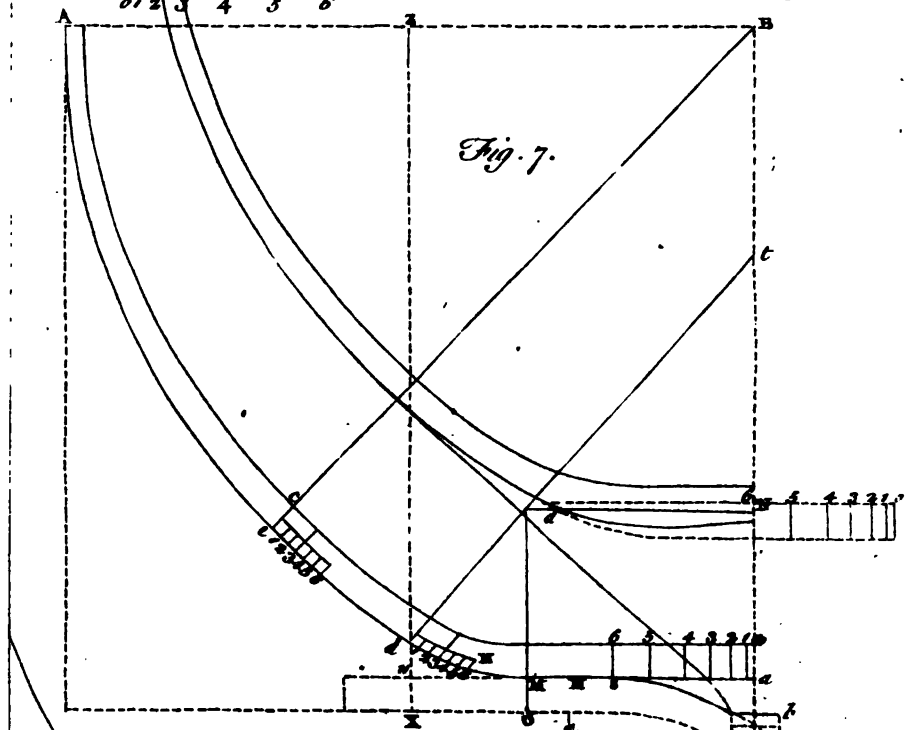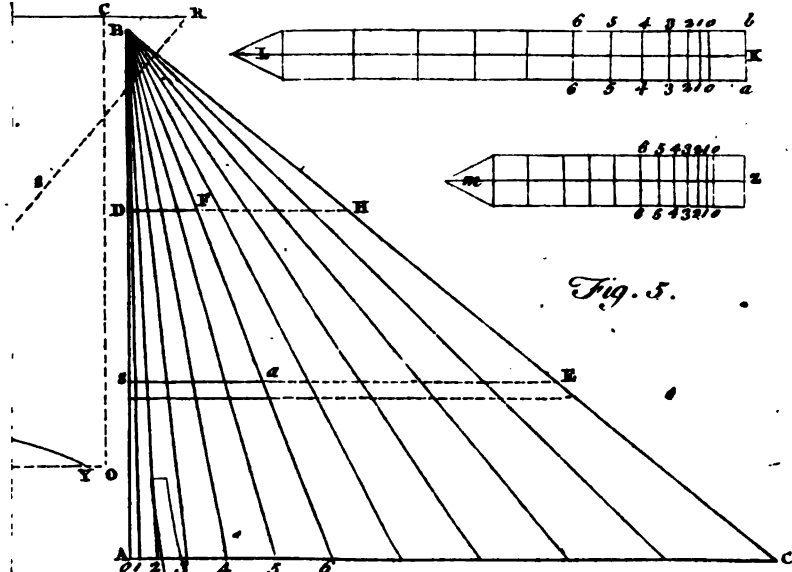
water it is not worth the regarding. But then by this calculation we discover that the ship is too lean before; for whereas the fore part should exceed the after part by 30 tuns, we find, by this calculation, that the after part exceeds the fore part by 193 tuns 1995 pounds.

Upon this account we must consider carefully if the midship frame is properly placed; it is here 5 feet before the middle. If the midship frame was exactly in the middle it would augment the weight of the fore part 102 tuns 307 pounds, and diminish that of the after part exactly the same quantity, by which means the fore part would be 1172 tuns 1014 pounds, and the after part 1162 tuns. Now we may fill out the fore part, so as to gain 15 tuns 636 pounds, which was deficient, to make the calculation taken from the draught agree with the real weight proposed for a ship of 70 guns fitted out for sea, with six months provision on board; and the fore-body will weigh 25 tuns 1255 pounds more than the after part, which may be judged sufficient.

C H A P. IX.

A Method to calculate the Resistance of the Water upon the fore Part of the Ship.

DAILY Experience sufficiently proves that the fluids, by their motion, attack the solids that oppose them, as bridges, mills, &c. with such violence as to carry all before them; and this is agreeable to the very nature of fluids.

For all fluids are an assemblage of a prodigious number of small solid bodies of a globular form, each of which being easily put in motion will act upon any surface with the same force that any other solid body of the like mass would do. But as these particles have but a very small cohesion with each other, fluids cannot act with the same force as solids which have their parts united.

A mass of water of 20 cubical feet will not act with the same force upon the pier of a bridge which opposes it, as a mass of ice of the same dimensions; because the whole mass of ice having its parts so united together, that one cannot advance without the other, it gives the blow with the united force of all the parts at once, whereas the parts that compose the mass of water, being but slightly united, they cannot act jointly or in concert, and they exert their force one after another; they indeed succeed one another immediately, and are a little united by their reciprocal pres-

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ſure; but as every part has its own peculiar velocity, ſo it makes its effort ſingly by itſelf, and, being eaſily put in motion, it will be as eaſily turned out of its direction, the parts being only retained together by the weight of thoſe that come next them.

Fluids have a continual effort, becauſe when a certain number have produced their effect they are ſucceeded by others as long as the current laſts.

Hence it will follow, that when a veſſel is left to a current of the river, it can receive no more velocity than the current has, and its velocity will be accelerated till it is equal to that of the current.

If, on the contrary, any floating body receives a motion in a contrary direction to that of the current, it will be continually retarded, till it has none, and then it will change its direction to follow that of the current.

We ſhall here remark, that it is indifferent whether we aſcribe the motion to the ſolid or to the fluid; for the impreſſion of the water upon the ſhip's ſtem is the ſame when under ſail, as when at an anchor, provided the motion of the current be equal to that which the ſhip acquires by ſailing.

The effort of fluids is as the ſquare of the velocity of the current.

It is very plain that the more rapid the current is, the greater will the impreſſion of the fluid be; for the parts will then ſhock the ſolid with greater force than when it runs ſlowly; ſo that the force is augmented in proportion to the velocity. Again, the number of the parts of the fluid that ſtrike the ſolid in any ſpace of time, is in proportion to the velocity of the current; for the faſter it runs the greater will be the number of the parts that ſtrike the ſolid in a ſpace of time; ſo that not only the effort of the fluid, but likewiſe the number of parts that attack the ſolid, is augmented in proportion to the velocity of the current, and when theſe two are united, the effort of the fluid will be in a duplicate ratio of the velocity; ſo that if the velocity be doubled, the ſhock will be quadrupled.

Hence, the faſter a ſhip goes through the water, the greater will be the reſiſtance ſhe meets with, and this will be augmented in a duplicate ratio of the velocity with which ſhe ſails.

The impreſſion of a fluid increaſes as the ſurfaces which oppoſe its current.

It is very plain, that if one ſurface is double another it will receive double the number of the parts of the fluid, and of conſequence the impreſſion will be double upon the ſurface, whoſe area is double the area of another ſurface. Hence thoſe ſhips whoſe midſhip frames have the greateſt capacity meet with moſt reſiſtance.

The efforts of fluids will be leſs when the ſurfaces are in an oblique poſition to the current, than when in a perpendicular poſition.

Plate

Plate IV. *Fig.* 7.]   Let E A reprefent the courfe of the fluid fetting per-
pendicularly on any body A B;   it is plain, that it receives the impreffion
of all the parts of the fluid contained between A and B; whereas, if the
point B be moved to D, the parts of the water contained betwixt B and
G will have no impreffion upon A D.   Hence the quantity of the fluid
which attacks A B is to that which attacks A D as A B is to A G;
that is, as the radius is to the fine of the angle of incidence E A D.   But
if there were no other advantage gained by this oblique pofition, than
being expofed to fewer parts of the fluid, it would be of very little
fervice to a fhip which muft have a fufficient breadth, fuppofe A B; it is
plain, the number of the parts of the fluid which give the impreffion will
be the fame, when the fore part of the fhip is in the form of A D B, as
when it is flat in the form of A B; but the fluid which exerts its force
on the furface A D B does not produce the fame impreffion as when it
exerts its force on A B, becaufe the direction of each particle of water,
which ftrikes any furface obliquely, may be refolved into two directions,
one perpendicular, and the other parallel to the plane.

In order to give us an idea of compound motions, and of the refolution
of their forces, let us fuppofe two rulers A A and B B, (*Plate* IV. *Fig.* 5.)
placed upon a plane at right angles to one another, and a fmall ball C pla-
ced at the angle of their meeting, it is plain, if we flide the ruler B B in
a parallel pofition to itfelf, it will carry the ball C along the edge of the
ruler A A; but if both the rulers be made to flide together, fo that they
ftill preferve the fame angle, in fuch a manner that when the ruler A A
arrives at the line VII, VII, the ruler B B arrives only at the line 3, 3.
It is plain, the ball will defcribe the diagonal of the parallelogram C,
VII, D, 3. the fides of which will be proportional to the diftance the ru-
lers have moved, that is, D, VII is to D 3 as 3 to 7; but if the rulers
be fuppofed to be moved equally, fo that when A A arrives at the line
VII, VII, B B fhall arrive at the line 7 7, the ball will defcribe the
diagonal C F of the fquare C, VII; F 7.

Now, if we fubftitute any other two agents in the place of the rulers,
fuch as two hammers, and both be fuppofed to ftrike the ball with equal
force at the fame time, it is plain, the ball will go in the direction of the
diagonal C F; but if the force with which one hammer ftrikes the ball
be to that by which the other hammer ftrikes the ball, as 7 to 3, then
the ball will move in the direction of the line C D.

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The principal Effects of Compound Motions. (Plate IV. *Fig.* 6.)

If two powers C and B act with equal force on the body A, that is to say, that the power C would drive to B in the fame time that the power B would drive it to C; in the contrary directions of the lines C A and B A, the body A will remain at reft; but if one of the powers acts with greater force than the other, the body will follow the direction of that which predominates, diminifhed by the quantity of the fmaller force.

2d, If two powers D and E act upon the body A in the fame direction, viz. in the lines D A and E A, the body A will follow the direction of both, and pafs through the point F, with this only difference, that it will go with greater velocity when impelled by both powers than with one.

3d, Let the two powers G and H ftrike the folid A, in the direction of the lines G A and H A, it will thereby receive a compound motion, the force and direction of which may be expreffed by the diagonal of a parallelogram, as was before obferved.

In order to conftruct this parallelogram, which is called the *refolution* of the forces, let the two powers G and H be fuppofed equal and ex-preffed by the lines H A and G A; from the point G draw the line E G equal and parallel to H A; from the point H draw the line E H equal and parallel to G A, and the diagonal E A (the refult of the two powers reprefented by the fides of the parallelogram H A and G A) fhall exprefs the velocity and direction of the compound motion; the effect of which will be, that the body A will be carried through the point F. But fuppo-fing the forces unequal, and let that of H, (*Fig.* 9.) reprefented by the line H A, be double that of G, reprefented by the line R A; then from the point R draw the line R S equal and parallel to H A, which fhall exprefs the force and direction of the power H; and from the point H draw the line H S parallel to R A, which will exprefs the force and direction of the power G; the diagonal S A expreffes the velocity and direction of the body A, which will pafs through the point T, whereas, if the powers were equal, it would pafs through the point F.

It may be remarked, that two attractive powers placed at P and Q, would produce the fame effect as two impulfive powers at G and H, and that the parallelogram may be conftructed on the lines A Q and A P.

C O N S E Q U E N C E S.

1ft. The acuter the angle of the direction of the power is, the nearer will they approach to one direction, and act with greater force; fo the refult of G and H is greater than that of K and I, fuppofing the powers to be equal.

                                                       2d,

2d. The greateft effect of two powers is, when they both act in the fame direction, and the leaft when they act in contrary directions.

3d. When two equal powers act in fuch a direction that they form an angle of 120 degrees, as A K and A I; in this and in no other cafe, the refult will be equal to the fingle force of A I or A K; it only changes the direction; for when the two powers act jointly, A will be carried to F, whereas if K only acted, it would be carried to T; or if I only acted, A would be carried to V; if L only acts it will be carried to V; if M only acts it will be carried to T.

4th. If the direction of two powers make an angle lefs than 120 degrees, as G A and H A, they will affift one another; but if they form an angle greater than 120 degrees, as L A and A M, they will be reciprocally diminifhed.

The Refults of a Motion impreffed upon a Body A, *in Relation to a Surface* a b, *which oppofes its Motion.* (Plate IV. Fig. 6.)

1ft. When a body ftrikes a furface obliquely it will be with lefs force than when it ftrikes it perpendicularly; for it may ftrike it fo obliquely as only to graze along it; between the perpendicular fhock, which is the greateft, and the oblique, which approaches neareft to a parallel to the furface, there may be an infinite number of directions, lefs or more oblique, and the furface will be ftruck with more or lefs force.

2d. If the two powers are united in D, they will act, in the direction D F, with great force upon a b; becaufe they not only act jointly, but likewife in a perpendicular direction upon the furface a b.

3d, If the two powers be equal in force, and act in the direction of the lines G A and H A, the body A will alfo fall perpendicularly on the furface a b, but with lefs force than in the firft cafe, becaufe of the obliquity of the directions.

4th. If the power H have double the force of the power G, then the direction will be changed into the line S A, (*Fig: 9.*) and the body will ftrike the furface obliquely in the direction of the line S T, but with lefs force than in the fecond cafe, not only on account of the diminution of the force of the power G, but alfo on account of the obliquity of the fhock.

5th. It will be indifferent whether the body A receives its impulfe from one fingle power, or from two, fo that it ftrikes the furface a b in the fame direction. Hence we fhall have no occafion to confider the powers which give the motion, but only the velocity and the direction in which they ftrike the furface.

6th. It will produce the fame effect, whether we change the line of direction

direction, in which the body A strikes the surface *a b*, or change the position of the surface *a b* in respect of the line of direction.

From what has been said, it will follow, that if the common effect of two powers acting upon the same body be known, and also the direction and force of one of them, then the direction and force of the other may be found; for let the body C (*Fig. 5.*) be carried to the point D by the action of two powers, and one represented by the line C, VII; draw the line D 3 equal and parallel to C, VII, and compleat the parallelogram, so shall C 3 express the force of the other power.

The Application of what has been said to the Shock of Fluids.

We have hitherto considered the shock of a solid body in different directions upon the surface of another solid, but we will readily grant that fluids do not act in the shock in the same manner that solids do. It is very probable, that when a fluid falls perpendicularly upon a surface, there is a mass of water that rests immoveable before the surface, which occupies the place of a solid body, and has nearly the same effect as if the surface was round, so that the fluid does not attack the body that opposes it in a direction perpendicular to its course; besides, the particles of water which attack a surface, whether obliquely or not, may rebound and change their direction, so that the laws of fluids are quite different from the laws of solids in the shock.

The oblique direction of a particle of water may be resolved into one that is perpendicular to the body which opposes its courses, and one that is parallel to it.

In order to construct this resolution, (*Plate* IV. *Fig.* 11.) upon the line A C inclined to the current, form the parallelogram A H E F (A E representing the velocity and direction of the current) making E F parallel to C A and E H perpendicular to C A. The diagonal E A, which represents a particle of water and its velocity, will be the result of a motion supposed to be produced by two powers, one parallel to A C, whose force and direction is represented by E F, the side of the parallelogram, and the other perpendicular to it represented by the side E H.

Hence it will follow, that when a surface is exposed to the shock of a current, in different oblique directions, the force of the direct shock is to that of the oblique, as the square of the radius is to the square of the sine of the oblique angle of incidence; for the effort of the particle E A, (which strikes the body A B, in a perpendicular direction,) is to the effort of the same particle E A; (which strikes the body A C in an oblique direction,)

as

as E A is to E H; but E A is to E H as A B, the fine of the right angle, is to A G, the fine of the oblique angle of incidence.   But it was before obferved, that the fum of the particles that ftrike A B is to the fum of the particles that ftrike A C as the radius is to the fine of the angle of incidence.   Hence, by multiplying the effort of one particle, by the number of particles that ftrike A B, (that is, the effort of the whole water upon A B) and multiplying the effort of one particle by the number of particles that fall upon A C, that is, the effort of the whole fluid upon C A) we fhall have the following proportion: The effort of the whole fluid upon A B is to its effort upon A C, as the fquare of the radius is to the fquare of the fine of the angle of incidence.

When the furfaces A B and A D, which oppofe the current A E, are unequal (*Plate* IV. *Fig.* 10.) the quantities of water which ftrike thefe furfaces are as the product of the furfaces by the fines of the angles of incidence; from whence we fhall have the following proportion: The effort of the fluid upon A D is to that upon A B, as the fquare of A G, the fine of the angle of incidence multiplied by the furface A D, is to the fquare of A B, the radius, multiplied by the furface A B.

CONSEQUENCES.

1ft. If two equal furfaces, expofed to the fame current, receive its fhock in different obliquities, the impreffions will be to one another as the fquares of the fines of the angle of incidence.

2d. A furface parallel to the current can receive no fhock, becaufe there is no angle of incidence.

3d. If two unequal furfaces are expofed to the fame current, the impreffions they receive by the fhock in different obliquities, are to one another as the products of the fquares of the fines of the angles of incidence, and of the furfaces that receive the fhock.

4th. If two equal furfaces receive the fhock of two unequal currents, the impreffions will be to one another as the products of the fquares of the velocities, and of the fquares of the angles of incidence.

5th. If two unequal furfaces are expofed to two unequal currents, which ftrike them with different obliquities, the impreffions will be to one another as the products of the fquares of their velocities; of the fquares of the fines; of the angles of incidence; and of the furfaces.

All thefe confequences may be deduced from the preceding principles; it only remains to apply them

Let A B (*Plate* IV. *Fig.* 4.) reprefent the extreme breadth of a veffel, and let the fore part be formed according to the angles A C B,

or A F B, or A L B. In order to find the efforts of the fluid, suppofing the velocity and direction to be the fame, and parallel to the keel, in the three cafes, upon the middle of the line A B, erect the perpendicular E L, which will pafs through the tops of all the triangles; then to find the fines of the angles of incidence, with the radius A B defcribe two arches, A F and B F, to interfect one another in the vertex of the equilateral triangle; the arches will interfect the fides of the angle, that is lefs than 60 degrees; but not the fides of that which is more than 60 degrees; produce one of the fides from C to M *(Plate* IV. *Fig.* 4.) Laftly, let fall the perpendiculars M D, F E, P K, upon the line A B, from all the points where the arches interfect either the fides of the triangles, or the fides that are produced; fo fhall A E, A D, and A K, reprefent the fines of the angles of incidence upon the different triangles A F B, A C B, and A L B.

It will be eafy to obferve, that the effort of the fluid upon the intire fore parts A C B, A F B, or A L B, is to the effort upon the extreme breadth, as the effort upon A C, A F, or A L, is to the effort upon A E; but it was proved before, that the impreffions received by two unequal furfaces, oppofed to the direction of a current, are as the fquares of the fines of the angles of incidence multiplied by the furfaces; fo, in this cafe, the impreffion on A C will be to that on A E, (or, which is the fame thing, the impreffion on A C B will be to that on A B) as the fquare of A D, the fine of the angle of incidence, multiplied by A C B, is to the fquare of the radius multiplied by A B.

We have alfo the effort on A F B to the effort on A B; as A F B, multiplied by the fquare of A E, the fine of the angle of incidence, is to A B, multiplied by the fquare of A B the radius. This proportion would fhew the effort of the fluid upon the prow A F B, in a perpendicular direction to the fides A F and B F, which would be very ufeful, if it were required to determine the dimenfions of the timber that is to refift that preffure of water; but in the prefent cafe, where only the relative effort upon the prow is confidered in the direction of the keel, we muft form another refolution. Let then C D *(Fig.* 8.) reprefent the effort upon F B, perpendicular to that furface; if from the point D we let fall the perpendicular D H, and compleat the parallelogram G C D H, C G fhall reprefent the relative effort upon the prow in the direction of the keel, fo the whole effort upon F B, may be reprefented by F B multiplied by the fquare of the angle of incidence, which is to the relative effort as F B is to E B: The relative effort then is equal to the fquare of the fine of the angle of incidence multiplied by E B, or by the fum of the particles which fall upon F B; fo to find the relative effort on F B, we muft

multiply

Fig. 5.

Fig. 6.

Fig. 7.

Fig. 8.

Fig. 9.

Fig. 10.

Fig. 11.

Fig. 1.
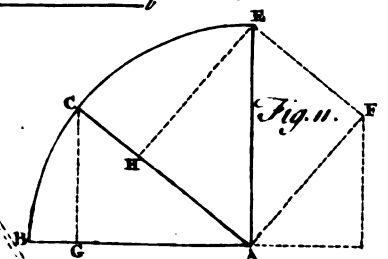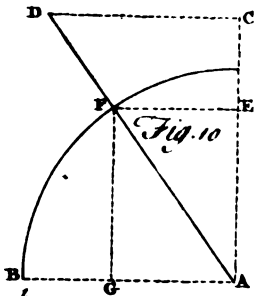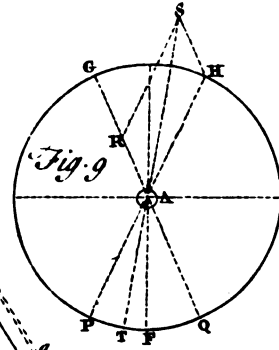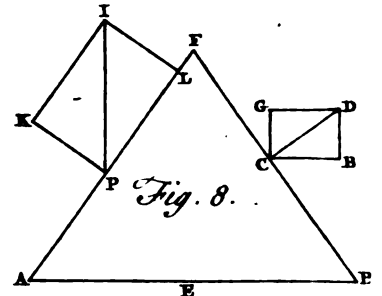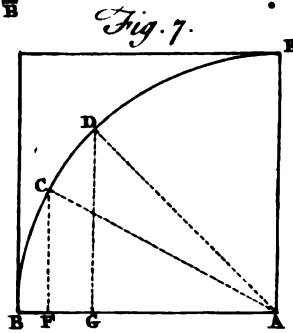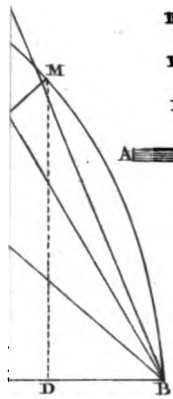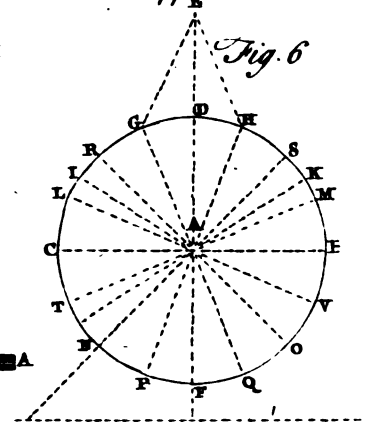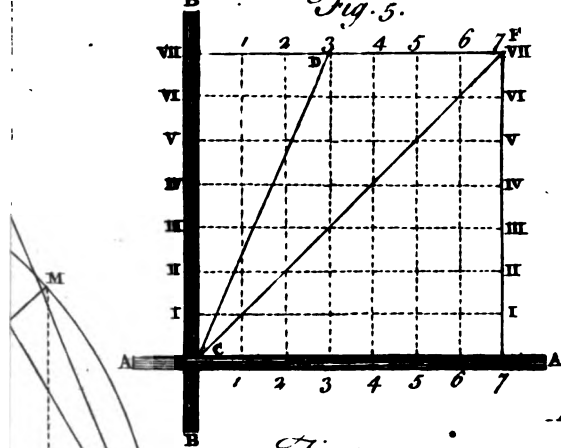
multiply the fquare of the angle of incidence by the projection of the plane F B upon the beam E B.

Tho' this method cannot be truly applied but to rectilineal triangles, yet, by dividing curves into a number of fmall parts, each may be confidered, without any fenfible error, as a ftrait line. M. *Bouguer* makes ufe of this method of approximation to a fufficient degree of exactnefs. What we have already faid upon that head, it is to be hoped, will facilitate this defcription to fuch as have only a flight knowledge of the mathematics; fo that all that remains now is, to apply this to the draught of a fhip of 70 guns, which has been already laid down.

A Calculation of the Refiftance of a Fluid upon the Prow of a Ship of 70 Guns, which we have laid down in a Draught, compared with the Effort of the fame Fluid upon the Area of the Midfhip Frame.

As the operations are to be performed upon the plane of projection before laid down, all the frames in the fore part muft be exactly formed as before in *Plate* II. in order to which it will be neceffary to make ufe of a larger fcale, as in *Plate* V.

It will be very convenient to draw the water lines I, II, III, *&c.* and the frames 1, 2, 3, *&c.* to the midfhip frame, at equal diftances from one another.

It is plain, that the water lines and frames divide the prow into trapezia, fuch as *r a*, 8 *b*, 7 *c*, *&c.* correfponding to the trapezium A D, and parallelogram *a d*, in the plane of elevation, *Plate* II.

It will be neceffary to obferve, that there muft be fo many water lines and frames, that the lines 8 *a*, 7 *b*, 6 *c*, *&c.* which are curves, may be efteemed ftrait lines.

We muft draw the diagonals *r a*, 8 *b*, 7 *c*, *&c.* through the trapezia; but we may take two trapezia at once near to the midfhips, becaufe the fhips fides are there nearly parallel to the current.

It will likewife be proper to obferve, that thefe diagonals are the projections of the diagonals of the parallelograms reprefented upon the plane of elevation, at leaft, on the furface of the fhip; as for inftance, the diagonal 8 *b*, on the plane of the projection, is the projection of the diagonal 8 *d* drawn on the plane of elevation.

Thefe diagonals divide the prow into the triangles 1, 2, 3, 4, *&c.* which ftrike the fluid with different degrees of obliquity.

We have not the entire areas of thefe triangles, by reafon of the curving of the prow, but only their projection on the midfhip frame; but this is all we want; for the fum of all the particles of water that ftrike the tri-

K

angles

angles are proportioned to the triangle projected on the midſhip frame, ſince the water that ranges along each triangle may be conſidered as a triangular priſm, the baſe of which is equal to the triangle *r a* 8, *Fig.* 1. *Plate* V. and this was the thing in queſtion. M. *Bouguer* propoſes to calculate the effort of the fluid on each triangle, their ſum will give the ſhock of the water upon the whole prow, and compare this to the ſhock of the fluid upon a ſurface parallel to the area of the midſhip frame.

To attain this, M. *Bouguer* lets fall perpendiculars to every frame, from the angles formed at the interſection of the water lines and the diagonals that were drawn to form the triangle; for inſtance, upon the frame 8, the perpendiculars *l b* and *r p*; upon the frame 7 8, the perpendicular 8 *m* on one ſide, and the perpendicular *n c* on the other ſide, &c.

This method requires that there be as many right angled triangles formed as there are triangles on the prow; and as there muſt be a great number of them, it will be neceſſary to find ſome method of forming them. The following ſeems to me to be the moſt expeditious.

Draw two parallel lines, B D and C R; let the diſtance betwixt them be equal to that betwixt the frames on the plane of elevation, and by this one operation we have the height of all the triangles that are contained betwixt the parallels.

As the baſe of all the rectangles ſhould be equal to the perpendicular of the correſponding triangle of the prow, we may ſet off the length of each perpendicular upon the parallel C R; ſo ſhall C H, *Fig.* 2, be equal to *r p*, *Fig.* 1; H L, *Fig.* 2, equal to *s a*, *Fig.* 1; L E equal to 8 M, &c. To compleat the triangles, draw the perpendiculars H N, L M, and the hypothenuſes D H, N L, &c.

If one of theſe rectangles be conſidered ſingly, D H may repreſent the radius, and C H will be the ſine of the angle of incidence.

All theſe triangles being deſcribed, we may begin to find their areas on the plane of the projection, becauſe it is upon this that the relative impulſe in the direction of the keel depends; which is the thing now required, as was before obſerved.

The ſurface of a triangle is found by multiplying half the baſe by the perpendicular; ſo the ſurface of the triangle *r*, *a*, 8, will be the product of the perpendicular *r p*, (equal to C H) multiplied by half the baſe *a* 8, and this will be the ſum of all the particles which ſtrike the triangle *r*, *a*, 8, which is an element of the prow of the ſhip.

In order to find the relative force of the fluid in the direction of the keel on that part of the bottom correſponding to the triangle *r*, *a*, 8, it is

only

only multiplying the ſurface of the triangle by the ſquare of the ſine of the incidence ; in place of multiplying it by the ſquare of the radius, which would give the impulſe the triangle would receive from the water in a perpendicular direction ; now if we divide this impulſe by the oblique one, the quotient will give the quantity that the impulſe is diminiſhed by the obliquity of the prow ; but there will be no occaſion for this laſt ſtep, for as the ſum of all the products of the triangles multiplied by the ſquare of the radius, gives the effort of the fluid upon the midſhip frame ; the direct effort may be found by multiplying the area of the midſhip frame by the ſquare of the radius, and if this be divided by the ſum of the products of all the triangles, multiplied by the ſquares of the ſines of the angles of incidence on each triangle, we ſhall know the diminution of the reſiſtance which the prow meets with in proportion to that of the midſhip frame.

It would be almoſt impracticable to multiply the ſurface of each triangle by the ſquare of the ſine of the angle of incidence, upon which account M. *Bouguer* ſubſtituted proportional lines in place of the ſquares of the ſines, which we ſhall now explain.

It was before obſerved, that if D H be the radius, C H will be the ſine of the angle of incidence.

If we let fall the perpendicular C O upon the line D H, we ſhall have the triangle D C H ſimilar to D O C ; ſo taking the equal lines C D, and N H for the radius, C O will be the ſine of the angle of incidence.

If we draw O P perpendicular to D C, the triangles D O C and C O P will be ſimilar, therefore the triangles D C H and C O P will be ſimilar, and D H is to C H as O C to C P ; but D H is to C H as D C to C O, and by multiplying theſe two proportions, the ſquare of D H will be to the ſquare C H as D C is to P C ; that is, if D C repreſent the ſquare of the radius, P C will be the ſquare of the ſine of the angle of incidence C D H. So the lines C P, H Q, L G, &c. give the ſquares of the ſines of the angles of incidence in the triangles 1, 2, 3, &c. which are to be multiplied by the ſurfaces of the triangles ; and the parallels D C, N H, &c. always repreſent the radius.

A Cal-

A Calculation of the Resistance of the Fluid upon the Prow of a Ship of 70 Guns, compared with that upon the Midship Frame.

Triangles.	Perpendicular.			Multiplyed by half the base.			Product.				Multiplyed by the square of the sine of the angle of incidence.			Product gives the effort of the water upon the triangle.			
1st.	f.	in.	lin.	f.	in.	lin.	f.	in.	lin.	poi.	f.	in.	lin.	f.	in.	lin.	poi.
1	6	6	0	1	9	6	11	7	9	0	3	2	0	36	10	6	6
2	5	7	6	1	6	3	8	6	7	10	2	8	0	22	9	9	0
3	4	6	6	1	9	6	8	1	7	9	1	11	6	15	11	2	8
4	4	6	6	1	9	6	8	1	7	9	1	11	6	15	11	2	8
5	2	9	6	1	8	6	4	9	2	9	0	11	0	4	4	5	6
6	2	8	0	1	9	6	4	9	4	0	0	9	0	3	7	0	0
7	1	11	6	1	7	6	3	2	2	3	0	5	0	1	3	10	11
8	2	2	0	1	9	0	3	9	6	0	0	6	6	2	0	7	9
9	1	4	0	1	7	6	2	2	0	0	0	2	6	0	5	5	0
10	1	4	0	1	7	6	2	2	0	0	0	2	6	0	5	5	0
11	0	5	0	1	6	6	0	7	8	6	0	1	0	0	0	7	8
12	0	10	0	1	7	6	1	4	3	0	0	2	0	0	2	8	6
13	0	2	6	1	6	6	0	3	10	3	0	0	8	0	0	2	6
14	0	4	0	1	6	6	0	6	2	0	0	1	2	0	0	7	2
15	0	1	0	1	6	6	0	1	6	6	0	0	3	0	0	0	4
16	0	5	0	1	6	6	0	7	8	6	0	1	6	0	0	11	6

The total effort of the first piece *r* V	104	2	8	8
Of the second	57	10	6	2
Of the third	43	8	6	5
Of the fourth	28	0	8	10
Of the fifth	12	9	8	7
Of the sixth	3	2	8	11
Total	249	10	11	7

We must in the next place find the direct effort of the water upon the area of the midship frame, by multiplying the area by the square of the radius.

OPE-

OPERATION.

Half the 6th water line *r* VI	10	2	0
The whole 5th water line V	20	0	0
The 4th water line	19	5	0
The 3d water line	18	1	0
The 2d water line	15	11	6
The 1st water line	12	0	0
The breadth of the keel	0	0	0
Total	95	9	6
Multiplied by the distance betwixt the water lines, which is	3	2	0
Product is the area of the midship frame	303	4	1
Multiplied by the distance betwixt the frames	8	0	0
Product	2426	8	8

This being divided by 249 : 10 : 11, the sum of the efforts of the fluid upon the triangles of the prow; the quotient is 9 $\frac{7}{10}$, which shews that the effort of the fluid upon the prow is to that upon the midship frame as 1 is to 9 $\frac{7}{10}$, which is a sufficient diminution of the resistance for a ship of this force. Hence we may conclude that the water lines in the fore-body are well formed, but a frigate will require more diminution, as will appear by the following examples.

The *Brillant*, as 3 $\frac{1}{4}$ to 1, a very bad sailer.

The *Tigre*, as 5 to 1, a company keeper.

A ship of 50 guns, designed by M. *Boyer*, but not built, as 8 to 1.

The *Monarque*, of 74 guns, 4 lb. shot, built by M. *Ollivier* in 1744, as 13 $\frac{1}{4}$ to 1.

The *Alcide*, of 64 guns, by M. *Ollivier*, at *Brest* 1741, as 6 $\frac{1}{4}$ to 1.

The *Renomme*, built at *Brest* by M. *Defalieurs* 1744, as 10 to 1.—This ship, by the account of the captain, was a very fine sailer.

The *Badine*, 6 guns of 3 lb. shot, as 7 $\frac{1}{4}$ to 1.

The *Panthere*, of 20 guns 6 lb. shot, as 10 $\frac{1}{4}$ to 1.

The *Amazon*, of 44 guns, built by M. *Blase Pengalot*, as 8 $\frac{1}{3}$ to 1.

The *Superbe*, built by M. *Helie*, as 5 $\frac{2}{10}$ to 1.

The *Mutine*, of 24 guns, built by M. *Geffroi*, senior, as 10 $\frac{3}{4}$ to 1.

We have compared the efforts of the fluid upon the prow of each ship, with that upon the plane, equal to the area of the midship frame.

It will be proper also to examine if the resistance in those be less than in ships which are known to be good sailers; but it may happen that a

L   ship,

fhip, whofe midfhip frame has a fmall area, may meet with little refif-tance, tho' her prow be not diminifhed in proportion to that of her mid-fhip frame; fo it will not be fufficient to know this proportion only, to be affured whether or not the fhip will be a fine failer. We muft alfo compare the areas of the midfhip frames, and not reft fatisfied with com-paring the efforts of the fluid, upon the prow of the fhip we have laid down, with that upon the prow of the fhip of the fame rate, which has gained a good character.

The firft Example of Comparifon.

We know that the area of the midfhip frame of the 70 gun-fhip, we have laid down, is 606 : 8 : 2, and that the effort of the fluid upon the prow is to that on the midfhip frame as 1 is to 9 $\frac{7}{10}$. Now if another fhip of the fame rate has the area of her midfhip frame 7 or 800 feet, fuppofing the fails, and every thing that may contribute to failing, to be alike in both; its plain this laft-cannot fail fo well as that we have laid down, and by this example, it is very plain, that if we would calculate which of two fhips would fail beft, we muft, after finding how much the refiftance of the fluid upon the midfhip frame of each is diminifhed by the form of their prows; alfo compare the areas of their mifhip frames, that we may know which of the two has the greateft mafs of water to difplace; but if it was only required to know, which of two fhips of the fame rate would fail beft, it would be fufficient to compare the efforts of fluids upon their prows.

The fecond Example of Comparifon.

We have found by the calculation, that the effort of the fluid upon the prow of our fhip of 70 guns, is 249 : 10 : 11 : 7; but if, by a like calcu-lation, we find the refiftance upon the prow of a fhip of the fame force, and carrying the fame quantity of fail, to be 300 feet, we may thence conclude that ours will fail beft.

It will alfo be proper to examine, by the fame calculation, whether the fhip we have laid down, can carry a good fail, drive but little to the leeward, and fteer well.

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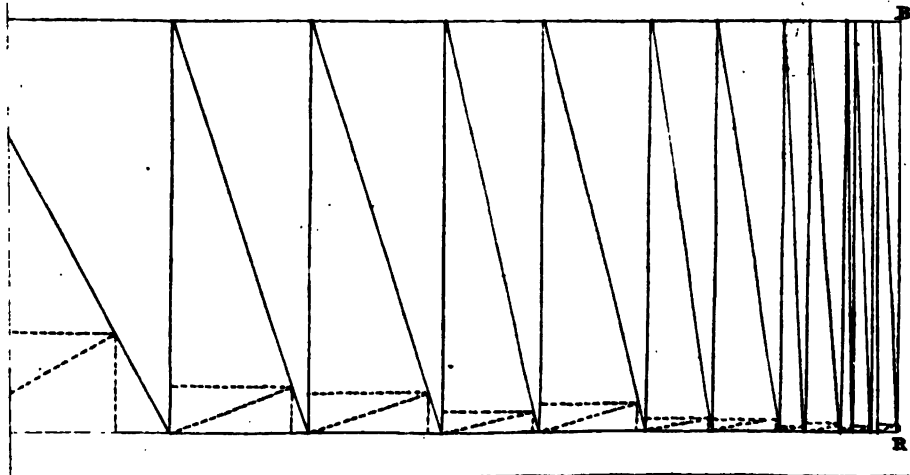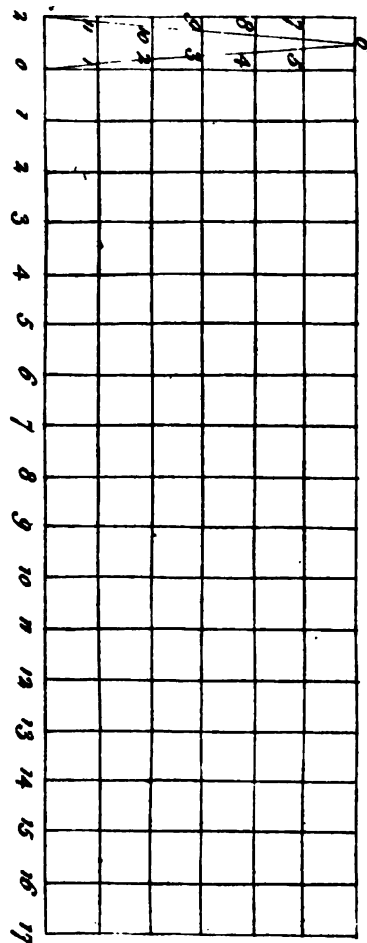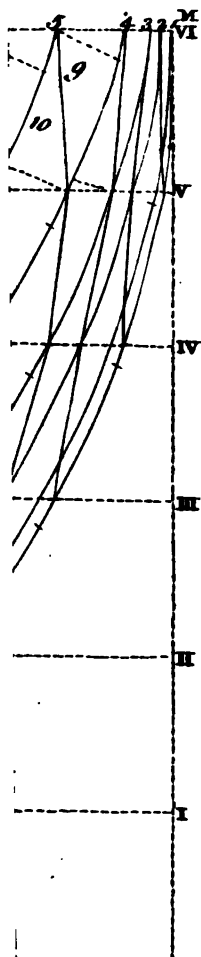
SUPPLEMENT

TO THE

TREATISE on SHIP-BUILDING.

CONTAINING

EXTRACTS

TRANSLATED FROM

M. BOUGUER's *Traité du Navire.*

TOGETHER WITH

M. DUHAMEL's Method of finding the Center of Gravity.

And fome Occafional REMARKS.

ALSO

An Account of feveral EXPERIMENTS, made to afcertain the FORM of a SOLID that will move with the greateft Velocity through the Water.

LIKEWISE

A Method to determine the Thicknefs of the Plank, in the Direction of the Planes of the Timbers.

With the Proportions for MASTS, YARDS, CAPS, &c.

By MUNGO MURRAY.

P R E F A C E.

IN grateful acknowledgment to the public, for their favourable reception of my firſt Edition, I have, in this Supplement, collected all the diſcoveries I could either make by my own obſervations, or gather from the writings of M. BOUGUER and M. DUHAMEL.

I have likewiſe endeavoured to determine the thickneſs of the plank in the direction of the planes of the timbers, and have illuſtrated it with a Plate engraved for that purpoſe ; Plate V. in the firſt edition, being too much crowded with lines, to admit of any addition.

Alſo an account of experiments that have been made to aſcertain the form of a ſolid that will move through the water with the greateſt velocity. Theſe experiments likewiſe ſerve to determine the propereſt poſition of the midſhip frame.

The proportions for maſts and yards, caps, tops, truſſel-trees, and croſs-trees, are inſerted.

Likewiſe the weights of the anchors, the dimenſions of the cables, the number, nature, length, and weight of the guns on each deck, according to the rates of the ſeveral ſhips in his Majeſty's Navy.

CONTENTS.

Of the Progreſs of Ship-building in *France*.

M. Bou-

CONTENTS.

Dimensions of the Masts and Yards.

SUPPLEMENT

TO THE

PRACTICAL TREATISE

ON

SHIP-BUILDING.

M. BOUGUER, in the Preface to his TRAITE DU NAVIRE, gives an account of the progrefs of fhip-building in *France*, with the names of feveral eminent men who applied themfelves, with much zeal, to reduce naval architecture to certain mathematical principles; and fays, that at a conference held at *Paris* in 1681, the principal dimenfions ufed in *France* were eftablifhed by an order of the arfenal. He makes mention of *Pierre Janffe Horn*, who, in the beginning of the laft century, imagined that *Noab's* ark fhould be made the ftandard and pattern of the form of a fhip: But M. *Bouguer* obferves, he did not confider that the ark, far from being defigned to fail with any degree of velocity, was built only to fuftain a great weight, when lying at reft on the furface of the waters of the deluge. Be that as it will, it feems, at leaft probable, that the firft defign of building floating veffels, was to carry goods from one place to another.

Now, the propereft veffels for that purpofe would be fuch as could contain the greateft quantity of goods, and carry them in the fhorteft time to the intended port: So that capacity and velocity feem to be two effential qualifications.

As to the firft, that of capacity, a circle has a greater area than any other plain furface of the fame circumference; and, confequently, a cylindrical tub would be the propereft form to anfwer the firft end, but the very worft for the fecond, *viz.* that of velocity: For, by what method foever the power that fets the veffel in motion is to be applied, it is indifferent what point goes foremoft; and if it were applied in an oppofite direction, the

veffel would go as faft a-ftern as a-head, if I may be allowed that expreffion, where there is neither head nor ftern.

A Cube is the next folid of greateft capacity; but this is fubject to the fame inconveniencies as the Cylinder: Hence we may conclude, that all floating veffels may be longer than broad.

An oblong rectangular parallelopiped will go with greater velocity endways than fideways; but it will be indifferent which end goes foremoft; and, befides, this form would meet with great refiftance in paffing through the water. For, let the component parts of that fluid be fuppofed never fo fmall particles of a globular form, it is certain they muft have fome kind of cohefion; and tho' they are eafily fet in motion, they muft actually be feparated before any body can pafs through them; and any plane moving in a direction perpendicular to itfelf, muft difplace as many of thefe particles as are contained in the area of that plane; and, as it advances forwards, will ftill have the fame number of particles to difplace, before it can go a-head; hence we may conclude, the parallelopiped will not anfwer the two effential properties.

Let us next examine, how far the wedge would anfwer thofe purpofes: This being tapered to an edge at the fore-end, will eafily divide the fluid, and the fides will attack the particles in an oblique direction, and confequently will meet with lefs refiftance in paffing through the water. If the particles of water were as clofely united as thofe of wood, perhaps the wedge would be the propereft form to force its way through a body of water. But it muft be obferved, that the wedge acts in a quite different manner, when cleaving a tree, and when dividing a fluid; for the parts that unite the tree are feparated at a great diftance before the wedge, and the parts through which it has paffed are fo far from endeavouring to unite themfelves again, that the extremity of the tree will be double its diameter afunder, before the wedge has advanced near the other end; whereas, the wedge has no fooner paffed through the particles of water, but they immediately unite as clofe as before, and none of the particles are feparated till the wedge actually ftrikes them, and no fooner has the wedge forced its way through any number, but it has the fame number to encounter, and drags a quantity of what is called dead water after it: for, placing a flat piece of wood in the water, at the after end of the wedge, it will keep clofe to it, till the wedge alters its direction; for which reafon, there feems to be a neceffity for tapering the after-end of the wedge. It muft likewife be obferved, that the mall that forces the wedge a-head drives it in a direction perpendicular to the after-end; whereas the wind that forces a fhip a-head, fometimes ftrikes it in a

direction

direction oblique to the keel, which will be apt to drive it out of the direction of the keel, as is the cafe of a fhip that lofes her rudder : This is another reafon for tapering a fhip at the after-end, for otherwife the rudder would have but very little power to keep her fteady in a ftrait courfe.

We have now found, that all fhips muft be longer than they are broad, and likewife tapered at each end : The next thing to be confidered is, whether or no the fides fhould be perpendicular to the bottom : In that cafe, all vertical fections perpendicular to the keel, and at right angles, would be parallelograms, which would be a very improper form for dividing a fluid ; for though, by the tapering at the fore end, the refiftance would be leffened, yet the particles fhould be fo far feparated as to allow the plane of the midfhip frame to pafs through them ; and though the effort of the fluid upon the midfhip frame would be greatly diminifhed by its oblique direction, yet as the fhip would then be as broad at the keel as at the water's edge, the bow would meet with great refiftance every time the fhip went about ; fo that there feems to be a neceffity, not only of tapering them at each end, but likewife from the extreme breadth down to the keel.

The next enquiry muft be, whether thefe vertical fections are to be limited with curve or ftrait lines, and how to afcertain their form.

The mathematicians have endeavoured to inveftigate the form of that folid which meets with leaft refiftance in paffing through the water ; but they have not drawn any practicable rules from thence, to determine the form of a fhip ; and fhould they be fo lucky, after a tedious calculation, as to find out the particular form of fuch a folid, it would be of little ufe in forming the body of a fhip : For it is fuppofed, that the folid is to continue in the fame pofition in the water, otherwife the immerged part will alter its form as often as it alters its pofition, unlefs it be, as M. *Bouguer* would have it, formed by the revolution of a curve round its axis. Hence we may conclude, that the particular form of a fhip cannot be determined by rules that will admit of a mathematical demonftration.

The builders, finding they could have very little affiftance from the mathematicians, have applied themfelves to experience ; and though they have not found any particular form which may be a ftandard for all fhips of the fame burthen, and defigned for the fame fervice, yet in fome points they feem to agree. Hence it is, that, in fhips of war, of the fame rate, the principal dimenfions are nearly the fame ; and in all fhips the midfhip frame is nearer the fore-part than the after-part. For,

finding

finding by repeated trials, that a maſt or tree, when tapered, will tow faſter through the water with the butt end foremoſt than with the ſmall end, they conclude it will be ſo in ſhips; though M. *Bouguer* thinks the only reaſon for towing the butt end foremoſt is, that the rope may not ſlip. The rules given us by M. *Bouguer*, for calculating the reſiſtance, ſeem to be deduced from the ſame principles as thoſe for aſcertaining what weight will raiſe any heavy body on an inclined plane, which may be effected with as great certainty as by weights in a pair of ſcales, as is proved by experiments.

If the particles that compoſe a maſs of fluid were ſolids of ſuch a particular quality, that when once ſeparated, they could not be united again, without the application of ſome exterior force, the ſame rules might anſwer in both caſes. But when it is conſidered that the particles of the fluid have a natural energy, whereby they unite themſelves as ſoon as the force that ſeparated them is removed, we may hence conclude that every particle has two motions, the one parallel, and the other perpendicular to the axis of the maſt. If the maſt were at an anchor, floating on the water, and a current ſetting parallel to its axis, the ſhock ſuſtained by the maſt would be the ſame as if the maſt were in motion, (with a velocity equal to that of the current) and the current at reſt. It ſeems probable, that the natural tendency the particles have to unite themſelves, will as it were graſp the maſt, and retard its motion, when the ſmall end is foremoſt; whereas, when the butt end is foremoſt, and hath once opened a paſſage, the particles, by their union, will rather force it a-head, or at leaſt prevent its going a-ſtern; and experience ſeems to favour theſe principles; otherwiſe a ſhip would go faſteſt ſtern foremoſt. M. *Bouguer* tells us, the reaſon for making ſhips fuller before than abaft, is, not to make them go with greater velocity through the water; for, he ſays, that would have a quite contrary effect, but to make them ſteer well.

Since capacity is an eſſential quality, the immerged part muſt be of ſuch a form as to be able to ſuſtain the whole weight of the ſhip compleatly rigged, with guns, ammunition, proviſions, ſtores, &c. The weight of all ſhips of war, of every rate, is now pretty well known; ſo that we may find, by calculation, if the load-water line be properly placed: But this is not all that is to be conſidered; great regard muſt be had to the velocity, ſtability, property of ſteering well, carrying ſail, and many other neceſſary and ſeemingly oppoſite qualities. How to attain all theſe qualities has been attempted by ſeveral eminent mathematicians and builders, who, inſtead of determining any particular form,

have

have produced as many different, and feemingly directly contrary rules, as there are different complexions and ftatures among the projectors.

The mathematicians have given certain rules for finding the center of gravity, both of the fhip when properly loaded, and alfo the center of gravity of the column of water fhe difplaces, M. *Bouguer* likewife gives directions how to ftow the goods, fo that the center of gravity may be properly placed with refpect to the *metacenter* and the center of gravity of the column of difplaced water; which laft cannot be altered after the fhip is built. It is on the proper fituation of thefe that the ftability of the fhip depends. As to velocity, they have given us rules for calculating the refiftance of the fluid on the fore part of the fhip: but unlefs it can be proved that the velocities are always proportional to the refiftances, it feems we fhall gain little by this; as there is no account taken of the after body, and in the calculations they fuppofe the fhip to be upright, and failing in the direction of the keel; whereas a fhip often lays her fcuppers in the water, when clofe hauled on a wind, and fometimes makes two or three points lee way, feldom lefs than one; and yet fome fhips in fmooth water will then fail within two or three knots as faft as when going large. We may venture to affert, there will be no proportion betwixt the velocities, and refiftances in thefe two cafes; for in the firft all the particles that ftrike the fore part loofe their power as foon as they pafs the midfhip frame; afterwards, according to his principles, they occafion no refiftance; whereas, in the fecond, every particle has its full force, acting on the whole length of the fide, and the area of the fection, which in this laft cafe would receive the perpendicular fhock, would be almoft double that of the midfhip frame; add to all this that there is room to fufpect thefe rules of being deduced from wrong principles, as was before obferved. But admitting all this, and that the velocities may be calculated, after the fhip is built, and found even by experience to be proportionate to the refiftances, what will that avail us, if we have no inftructions how to form the body fo, as to be capable of the greateft velocity, in all pofitions, confiftent with the requifite capacity, ftability, &c? There are other very material points to be confidered, fuch as the center of rotation, or the axis on which the fhip turns when fhe inclines to one fide, when fhe tacks or pitches; thefe are continually fhifting, as is the point of fuftentation or fufpenfion.

In all branches of the mathematical fciences, there are certain theorems demonftrated, from whence the practical rules for the folution of various problems are deduced, in which there are always fome neceffary *data* given, by which the unknown things may be difcovered.

It

It is to be wished we could proceed in the same manner, and with the same certainty, in ship-building ; but I do not find that any who have treated that subject have given us any invariable rules for settling these points ; and indeed, considering the infinite number of properties, and in some cases so opposite to one another, that if any of them be pursued to too great a degree, it will destroy another very essential quality. I say considering all these things, it will be a very difficult task, if not impossible, to unite them all in one body ; add to this that the different seas, and different services in which they are to be employed, will require as different forms ; so that theory alone, without actual experiment, seems insufficient to reduce this complicated art to a regular system. I shall just mention some of the necessary *data*.

1st. The whole weight of the ship compleatly rigged and boarded.

This is generally given, both in ships of war, and in those for the merchant service, being what is generally understood by tuns ; that is, builder's tuns ; but the true tunnage of most ships of war is now pretty well known, as the number and weight of the guns, provisions, &c. of each rate is established.

2d. The length of the gun deck.

This in ships of war may be nearly determined by the number of guns.

3d. The breadth.

If the section of the load-water line were a regular curve, the length would determine this, and its area might be calculated ; and converting the whole weight into cubick feet of salt water, and dividing those by the area of the load-water line, we should have the depth or draught of water ; that is, supposing the form of the body to be that of a bathing tub, which perhaps would be very proper for carrying goods in a canal, where it might be dragged by horses ; but as ships are to encounter high seas, and sustain the violence of storms of wind, it is plain they will require a quite different form.

4th. The depth of the hold, and draught of the water fore and aft.

5th. The extreme breadth of three sections at right angles to the keel, and perpendicular to the plain of flotation ; and likewise the extreme heights of these breadths, together with the breadths and heights of the top-timbers of these sections ; one of them to be near the middle, another at the after end of the keel, and the third at the beak head.

6th. The rake of the post and stem.

7th. The situation and exact form of the midship frame and likewise of the other two vertical sections ; and if to these three we add the other

two

two which M. *Dubamel* calls the balance frames we may fafely fay the whole form of the fhip is determined.

The great difficulty will be to obtain thefe *data*. M. *Bouguer*, and after him M. *Dubamel*, hath purfued this fubject as far as the nature of theory is capable; from whence they have deduced feveral ufeful practical inferences, but have ftill left thefe points undetermined, and at laft refer us to the general practice of the moft experienced builders. So that what improvements have been hitherto made feem chiefly owing to experience; and fome think it highly probable that the form which comes neareft nature, fuch as that of the fwifteft fifhes, will beft anfwer the purpofes of fhipping. But here we fhall find ourfelves very much embarraffed; for fifhes are wholly immerged, and the force that moves them is wholly in their own power, and they are in no danger of being drove out of their intended courfe by an external force, the author of nature having furnifhed them with every thing that is neceffary, either for purfuing their prey in a direct courfe, or turning themfelves as occafion requires; whereas in a fhip, it is quite otherwife, as fhe is entirely fubject to an external force, and governed by the helm; and therefore her form muft be fuch as may be moft capable of receiving thefe impreffions, and what nature has denied her, muft be fupplied by art.

As all who have written on this fubject have left thefe points undetermined, I fhall not attempt it. I have in the appendix to the firft edition abridged the fubftance of what M. *Dubamel* has faid in his treatife, and in this Supplement fhall extract fome of M. *Bouguer*'s fundamental principles, together with what M. *Dubamel* has advanced on the center of gravity in his fecond edition; which I fhall endeavour to tranflate fo as to be intelligible to thofe who do not underftand the *French* language, and, as occafion offers, make fuch remarks of my own as I think neceffary.

EXTRACTS

EXTRACTS

M. BOUGUER's *Traité du Navire.*

M. BOUGUER divides his Treatife into three books, the firft of which contains a general idea of the conftruction of fhips, and divers remarks on the common rules, in three fections.

In the firft fection, which he divides into twelve chapters, he defines the names of the different pieces that form a fhip, and their proportions, according to the practice of the moft eminent builders; and likewife defcribes the various methods ufed by them in forming the timbers. This takes up the firft nine chapters; for which we refer to M. *Duhamel*, who has given us the fubftance of what M. *Bouguer* has faid on thofe heads, as tranflated in the Appendix.

In the 10th and 11th chapters, M. *Bouguer* makes fome remarks on the form which the common rules gives to a fhip, and by what methods they may be amended.

It would be needlefs, fays he, to give any further account of the feveral methods ufed by builders to form the figure of their fhips, and project the frames; but it feems that all thefe prove, beyond difpute, that they have not yet found out a fixed rule. The only reafon why they have ufed fo many different methods, is, becaufe they could not find the beft. It would have tended much more to the advantage of their art, if they had in practice kept by one general rule, and only changed fome particular circumftances, carefully remarking the refult of fuch a change.

Experience would have proved the beft means of bringing naval architecture to perfection, if the thing had been poffible; but it is plain, that practice alone is infufficient in many cafes; for, though fome points may be determined thereby, yet, with refpect to many others, it ftands in need of theory. As nothing but a fincere defire of finding the truth, has engaged us in thefe refearches, we fhall not fail to take proper notice of what is good in the common rules, and fhall fupport them by all the arguments that may occur to us. I imagine the midfhip frame might

be carried further forward, and placed, not at $\frac{5}{11}$ of the keel, but at $\frac{5}{11}$ of the length of the immerged part, or even a little nearer the head. Thus it would always be nearer the fore part than the after part; the fore part would be fuller than the after part, and the immerged part would have more of the form of a fish.

It is well known, that the extreme breadth of every frame is higher abaft and afore than in the midfhips, but more on the aft part, which will make the fhip draw more water abaft than afore, about one fixth part of the depth of the hold. As the fore part cannot fo readily divide the water, when the keel is perfectly level, as when it is inclined to the ftern, it being uncertain what property to afcribe to it, the moft eligible me-thod would, doubtlefs, be to try the refult at fea, and make choice of what experience indicates.

Seamen, no doubt, tried to find her beft failing trim when at fea; and having frequently remarked, that it was neceffary to make her draw more water abaft than before, they eftablifhed it as a law, by obferving it; whereby we fhall at leaft gain this advantage, that the fhip will anfwer her helm better. This will occafion the decks not to lie parallel to the keel; for, admitting they may be of the fame height afore, that they are in midfhips, they are raifed confiderably higher at the poft, about the fixth part of the depth of the hold.

Now, taking what we have faid for granted, the builders, after all their trials, are very far from having found out the true figure of the bow, from whence almoft the whole of the round fhould be taken away.

The decks being fixed will determine the height of the beams; fo the decks will be no where fo high as the extreme breadth of the frames, but in midfhips. There is another important reafon for raifing the breadth higher afore than abaft, though few attend to it. When a fhip is clofe hauled by the wind, and lays much over the weather fide, it will lofe much of the breadth; whereas, on the contrary, the lee fide will gain confiderably. The fhip then difplaces a great deal more water on the lee fide, and, according to the manner in which fluids act, fhould be fupported with greater force, and of confequence be able to carry the greater fail. Hence it is plain, that, by raifing the breadths, we keep them as a referve, to be ufed when the fhip ftands moft in need of re-lief; that is, when fhe lays moft over. It may be remarked, that the flat floored fhips have leaft need of raifing the breadths; for, carrying all the weight of their cargo fo low, they are thereby capable of carrying a great deal of fail. Though we cannot abfolutely condemn the practice of making

making a ship draw more water abaft than afore, yet we cannot approve of any of the rules that the builders have given us to determine the exact difference.   A ship may be built to a precise draught of water, by which the construction will be founded on true principles; but when a ship is not built to one precise draught more than another, which is the case of most of the ships that have hitherto been built, it will be very difficult, and one of the most complex questions in naval architecture to determine this precise point: One would imagine there is no more to be done but to make the ship swim in the water, so as to be capable of carrying the greatest sail; but when a ship is very deep in the water, this will greatly increase the resistance, and of consequence be very prejudicial to her sailing.   We need not absolutely find that part which will meet with least resistance : When a ship has but little hold in the water, she can carry but little sail, and therefore cannot go so fast through the water. The resistance then must be calculated, not absolutely, but relatively, in proportion to the canvas she spreads.   This will be a most laborious and tedious calculation, as not only the various and irregular curves which compose the body must be nicely examined, to ascertain the resistance in different draughts of water, but likewise the weights of every part in the ship, and in what manner they are stowed; all these must be given before we can determine, in every case, the power that will be sufficient to sustain the force of the wind; on which account, it will be proper to advise the mariners to make frequent experiments of the ship's feat in the water; for the solution of this problem is only an approximation, even when the minutest circumstances are considered.   It is true, some builders, who would not be stopt by any difficulties, even such as puzzle the greatest mathematicians, have imagined they could find out this by another method.   Many of them pretend to examine the difference of the draught of water when the ship is launched, and would have it to be the same when the ship is loaded; our readers cannot but pity us, to be obliged seriously to confute these and such parallel maxims.   If a ship sails best when loaded to the proposed load-water line, she cannot sail so fast when she draws only one half, or one third part of it : So there can be no manner of proportion between a ship's draught of water, when launched and when loaded : And this method proposed so mysteriously to us by the *gens du metier*, and received with too much respect by many mariners, serves only to confirm us in our opinion, that very little regard should be had to all their other rules.

But if these common maxims are found so imperfect, it must be owing chiefly to the figure they give their ships; for it is impossible to

discover

difcover, by practice alone, and by experiments, though never fo often repeated, all the properties of an entire furface, which is an affemblage of an infinite number of curve lines and points. There can then be no manner of doubt but it is in this very article the art ftands moft in need of amendment. In general, the fore part is too full, and on that account the ribbands that form it are too round. The mariners are very fenfible that part fhould not be too fharp, but they have not adverted that it will be fufficient for that purpofe to carry the midfhip frame further forward. It may be, that, confidering all thefe particulars, we cannot always rigoroufly follow the precepts of theory, but it will at leaft be of great advantage to know them, that we may have the point of perfection always in view, even when we cannot arrive at it, but are obliged to ftop fhort of it.

If the floor ribbands were formed only by narrowing the breadths of the frames, without any rifing, and terminating the fore part at the extremity of the keel, this would occafion the ribbands to be perfect ftrait lines; by this means, the foremoft frame would be a rectangle, and the bow formed by two vertical planes interfecting one another in a vertical ridge at the extremity of the fore part, where they would form an acute angle. *Fig.* 1, reprefents fuch a bow, wherein the ribbands C A, F D, cannot fail of being ftrait lines.

But if we give a rifing to the frames, and cut off the bow by the fore part of the keel, as in *Fig.* 2, the ridge A D, or common fection of the two vertical planes, would run fo far below it, as is D F, the whole quantity of the rifing, and fo the bow could not be formed by plain furfaces; the ribbands would become curves, and the more fo, by raifing the point D, or augmenting the rifing D F: At the fame time that the figure would be more advantageous, it would approach the nearer to a *maximum maximorum*, in which refides the higheft point of perfection. In fuch a cafe, the fore part would be the figure of a regular demi-conoid; its bafe, inftead of being circular, would be a rectangle.

But what is principally worthy of our notice, is, that, according to the common dimenfions of fhips, it always happens, that when the rifing is the greateft poffible, and that all the vertical ridges at the extremity are vanifhed, and the fore part has by that means acquired the moft advantageous figure of any, the ribbands alfo, having acquired their greateft curvings, will round no more than the arch of a circle of 18 or 20 degrees; or, which is the fame thing, they differ fo little from a ftrait line, that the round in the middle is but the twentieth, or the two and twentieth part of the whole length. Now, taking all this for granted; the builders,

builders, after all their trials, are very far from having found out the true figure of the bow, which they have been obliged to make almoſt ſtrait; ſo far they are from knowing that rule, which would be ſo very uſeful to them, and which they may regard as the ſecret of their art; namely, that the leſs the riſing F D (*Fig.* 2.) is, or the lower they carry it on the frames afore, ſo much the ſtraiter will they make all the ribbands C A, E D, &c.

What we have advanced here depends on a very complicated theory; one may be very eaſily deceived, ſeeing the two points which limit the curve are ſo very near one another, that they will make the ribbands quite ſtrait, as in *Fig.* 1, or give them ſcarce the round of an arch of a circle of 18 or 20 degrees, as in *Fig.* 2; they will acquire this laſt by increaſing the height of the riſing line afore; whereas, by diminiſhing the riſing, the ribbands will come nearly ſtrait. We may, by a diligent attention to this ſingle maxim, without adhering ſtrictly to ſpeculative rules, reap the fruit of the whole; we may keep the form of the midſhip frame, but we ſhall gain much by making the extreme breadth no more than the fifth or ſixth part of the length, if at the ſame time we diminiſh the depth proportionally. This we ſhall clearly demonſtrate, in another place, and likewiſe this moſt ſurpriſing circumſtance, that by diminiſhing theſe two dimenſions, or by increaſing the length, a ſhip may be made to go ſome times as faſt as the wind.

Let us now again return to the ribbands, which may be equally ſpaced on the ſtem, and likewiſe on the midſhip frame, from the head of the floor: It will ſuffice to make them round no more than the twenty-fifth or thirtieth part of their whole length, whether we make them arches of circles, or ellipſes, and then there is nothing to hinder them from being formed in the ſame manner they uſe to make a fair curve.

By this means it will be eaſy to give the bow nearly what figure we pleaſe. After having formed the midſhip frame A D 2 A, *Fig.* 3, and projected the ribbands A W, G Z, &c. take the length of one of theſe, for inſtance, if W A, the breadth ribband, make the ſtrait line W A (*Fig.* 4.) equal thereto, and at the end of it W, draw the perpendicular W v, which may be made equal to W A, as the point v may be aſſumed at pleaſure, and draw the line v A, on the middle of which erect the perpendicular B C, which muſt be the 25th or 30th part of the line v A, when that happens to be the length of the ribband, but when it is ſhorter, as in this caſe, where it is only the projection of it, B C muſt be the 10th or 12th part of it. Then deſcribe an arch of a circle thro' the three points A, C, v; and dividing the line W v into as many equal parts as

there

there are to be frames before the midfhip; draw lines thro' the feveral divifions D, E, G, &c. parallel to W A, to interfect the arch v A. Thefe transferred to the line W A, will fpace the frames properly upon the ribband projected in *Fig.* 3, and will become an arch of an ellipfis, which will have but a very fmall curving; after the fame manner the other ribbands may be divided; it muft only be obferved that by reafon of the rake of the ftem the breadth ribband will be longer than the reft; their lengths muft not be reprefented by the line W v but by a fhorter R Q. In order to afcertain this length, fuppofe of the firft intermediate ribband of which S F is the projection, in *Fig.* 3; if it happens that R A is equal to S F it is only transferring the lines R 1, R 2, R 3, &c. to the projection of the ribband, which will give the proper fpacings of the frames, but in general produce the line v W, and from any point K, taken at pleafure, draw ftrait lines to the points 1, 2, 3, &c. thefe lines will divide the line S F proportionally to R A; and by this method we may form as many frames as we pleafe. Inftead of erecting the perpendicular on the middle of the line v A, *Fig.* 4, we may have it at the third part of it, making A B double of B v; the curve A C v muft then be formed by two arches of different circles whofe centers muft be in the line C B produced, by ufing the fame procefs; in all other circumftances we fhall imitate that curve which is propereft for dividing a fluid.

The after part may be formed by much the fame method; the ribbands fhould be almoft ftrait, not rounding in the middle above the 25th or 30th part of their whole length; thus the whole fhip will be nearly the form of two demi-cones, as in *Fig.* 5, whofe bafes unite at the midfhip frame, which feparates the fore from the after part, and fhould be placed as was before obferved, at $\frac{1}{12}$ of the whole length from the point B, the extremity of the fore part, whereas the general practice is to preferve the whole body, or a confiderable fpace, nearly of the fame bulk, and at the fame time it will be as faftened to the keel. Although the part A F G, which extends at fuch a diftance beyond the keel, may appear to be ufelefs, yet it cannot be wholly retrenched, becaufe of neceffity the rudder muft be faftened to the ftern poft G A. As to the part B C F, it might in a great meafure be taken away, if it could be done without prejudice to the faftening of the members together, which is fo requifite in forming the body, and were there not another very important reafon for not retrenching it, and that is becaufe this will conduce very much to her keeping a good wind, when plying to windward: It is true it will be a great difadvantage to her in wearing, and make her very fubject to broach

too,

too, but to remedy this we need only give her the more head fail, fo that we may without any inconveniency unite all thefe advantages.

It muft be remarked, that when fuch a fhip is formed fo as to fail on an even keel, we fhall gain nothing by making her draw more water abaft than afore, the refiftance which the fore part meets with in dividing the fluid is leffened very little, or fcarce perceptible; on the other hand, the rudder cannot fail of producing its effect, becaufe the water will eafily ftrike it with its whole force. When a fhip goes on an even keel, there is nothing to hinder us from laying the decks parallel to the keel, it is likewife plain there will be no occafion for laying the wing tranfom fo high, it will be fufficient to make it higher than the depth of the hold, about the eight or ninth part of that depth.

All that we have faid belongs chiefly to frigates, that are built on pur-pofe for failing, without regarding their capacity for carrying heavy goods. But when this is required or when it is neceffary to have feveral decks, and to carry guns, &c. we then form the bow according to *Fig.* 6. At the fame time we make the whole immerged part fuller, which will contribute much to prevent her pitching. *Fig.* 6 is only a fketch to reprefent things in general; the builders no doubt can reconcile all the angles, and breaches, or ridges of this figure: If we give the bow as much rifing as poffible, all the curves which end at the extremity A, will then become arches of circles, of 18 or 20 degrees; but in diminifhing the rifing, and making the ribband E D horizontal, that will become quite ftrait; the other ribbands as C M will likewife become ftrait and parallel to the firft, for the whole fpace intercepted betwixt the planes B F E C, and N D M. But the rake of the ftem, together with the inclination of the fides of the foremoft frame B F E C, will occafion the upper ribbands to be curves; the furface D M C E will be a plane, if the fide E C of the midfhip frame be a ftrait line; whereas becaufe E C is commonly a curve it will become cylindric, and in every cafe D M will be perfectly equal to E C. When the flat E F of the midfhip frame is half the extreme breadth, the half breadth L M, which is equal to H C, will be half of G C; fo the breadth N M of the bow, above D, at the extremity of the keel, will be equal to B C, half the extreme breadth. It will be needlefs to infift on the manner of defcribing the frames; it is plain that each of them, as P R S T, will be formed by two parts perfectly equal to thofe B F K, and H E C of the firft, but they approach to one another. The diftance R S, at which they muft be placed, will be the flat of each floor or frame, and that flat will diminifh in proportion to the diftance from D, the extremity of the keel. In regard to the part A N M D, it may be

formed

formed by producing each ribband, as C M, by an arch of a circle A M C M, a ftrait part of the ribband being a tangent to it in the point M ; this will occafion the whole ribband C M A to be rounder, which will be more fo if we make the flat F E of the midfhip frame lefs, fince H C becomes greater, and L M is equal to H C. This bow, whether we imitate it only in the principal particulars, or conform to the whole, will meet with greater refiftance in paffing thro' the water than that fhewn before : But the great breadths which are carried high, from B I C, the firft fection, to the height above the exremity of the keel, will at leaft make them more capable of fuftaining the weight of the fails. This form will make the fhip more capable of refifting the violent pitchings, occafioned by the feas ftriking one end of the fhip, which lifts it up, the other end at the fame time being plunged into the water, continues to fink till it is ftopped by the refiftance of the water, or by the weight of that column of water it difplaces. Sometimes the fhip is not fhocked; it is only the fea that loofes its horizontal pofition by the agitation of the furf or waves ; the fea all of a fudden withdraws itfelf from the bow, or from the buttock, which of neceffity will occafion that part of the fhip to fall down till it find a fupport : Thefe violent motions may occafion the carrying away of the mafts, and will always be prejudicial to her failing. It is plain there can be no way of preventing, or even diminifhing thefe accidents, but by making them fuller both afore and abaft ; we muft have recourfe to experience to form the fhip fuitable to the particular fervice fhe is defigned for ; but it is always to be remembered, and it is demonftrable, that when we have only velocity in view, and are to fail in fmooth water, as in the *Mediteranean*, with fine weather, the form of the fhip fhould differ very little from two cones joined together by their bafes. In fhort, if the fhip is not full enough for the purpofe, we may continue the whole breadth for a confiderable fpace ; the fifth, fourth, or at moft the third part of the whole length, and then form the fore part by the preceding rules. It feems to me, that when we have got a fufficient capacity in the hold, we fhould raife the floor ribbands afore ; otherwife, the bow would too much obftruct her failing. This laft property is chiefly to be obferved in fhips of war, where the breadth is continued ftrait but a fmall fpace. If, inftead of fuch a veffel as is commonly built for a tranfport fhip, we fhould build a fly-boat ; we need only take for a model the figure of a rectangled parallelopiped, and form the fore and aft part by two inclined planes, giving the ftem and poft a rake. We muft be always careful to preferve the two parts reprefented by B C F, and F G A, *Fig. 5*.

As

As to the rake, if the whole length of the ship be 144, the rake of the stem may be about 44, and when the breadth is continued for a good space it may be 32, and 68 for the rake of the stern post. That form of a fly-boat, where we need only round off the corners, will be the most perfect of any ; and, besides, as a great part of the side is strait, it will be thereby proper for carrying guns, and fit for a ship of war.

In the twelfth chapter, which concludes the first section, he shews the manner of launching a ship.

In the second section, our author treats of the furniture of a ship ; such as the rudder, capstan, and pumps, which takes up the first two chapters. The third chapter is on the cables and anchors.

The cables and anchors, says he, are of indispensible use to hold a ship when in a road-stead, where she is often exposed to all the fury of the wind and the sea. Every ship has at least five or six cables of different dimensions ; and to regulate the largest, which is called the master cable ; they make its circumference the 24th part of the extreme breadth ; or, which is the same thing, one inch to every foot of the half breadth. Suppose a ship to be 48 feet extreme breadth, the master cable should be 24 inches circumference ; but if the ship be 20 feet broad, the cable will be 10 inches ; and the dimensions of the other cables will be less, and is always estimated by their circumferences. In *France*, the length of all cables, whether great or small, is 600 feet, or 120 fathoms ; for a fathom is always accounted five feet.

It is necessary to have the cables longer, on which account, they are obliged to splice several to one anothers ends ; but it will be very difficult to make them longer in one piece ; the first threads that form them are of double the length, and more : Those of a cable of 120 fathoms long are 180, so that they loose a third part of their length in twisting them in the manner they do, to make the cable. These threads must be in length and proportion to the proposed length of the cable, the execution of which will be attended with difficulty.

One thing may be remarked, which may serve in all the different sorts ; that the weight of one fathom of cordage, in pounds, is nearly the fifth part of the square of its circumference. This rule will always be pretty exact, especially, when there is not too much tar put in the yarns ; as for instance, the weight of a fathom of cable of 24 inches, will be found, by multiplying 24 by 24, and dividing the product by 5, to be 115$\frac{1}{5}$ pounds, and the whole cable, which is 120 fathoms long, will weigh 13824 pounds. The weight of one fathom of a cable of 10 inches will, by this rule, be 20 pounds ; for 20 is the fifth part of 100,

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the fquare of 10; and the weight of the whole cable of confequence will be 2400. The weight of a whole cable may be had at one operation, by multiplying the fquare of the circumference by 24.

The cables would be ufelefs without the anchors, the form of them is to be feen in *Fig.* 7, which is the propereft figure for catching hold, in the fand, or in the mud, in the bottom of the fea. The anchors in *France*, *England*, and *Holland*, are of forged iron; but in *Spain* they may be feen of copper, and likewife, in feveral parts of the *South Sea*.

The part A D, is called the fhank, at the extremity of which there is a ring E; A B and B C, are the two arms, K C and I B, the fleucks; the ftock F G, which is of wood, is fixed at the end of the fhank, at right angles to the fleucks; the ufe of this is to make the anchor fall, fo that one of the fleucks will infallibly catch the ground. The two arms generally form the arch of a circle, of which the point H, is the center, being three eighths of the fhank from the point A; and each arm is equal to three eighths of the fhank, or to the radius; fo that the two arms together make an arch of 120 degrees: The fleucks are half the length of the arms, and their breadths two fifths of the length of the arms. In regard to the thicknefs they generally make the circumference at the throat A of the fhank, about the fifth part of its length, and the fmall end two thirds of the throat; the fmall end of the arms of the fleucks, three fourths of the circumference of the fhank at the throat. Thefe dimenfions fhould be bigger, when the iron is of a bad quality, efpecially when we ufe caft, inftead of forged iron.

When thefe dimenfions are obferved, an anchor of 16 feet 9 inches long, will weigh about 7000 pounds; for the workman making fome of thefe parts not exactly to the dimenfions, will caufe a confiderable difference in the weight: But if all anchors were fimilar, which they fhould be, their weights would be in proportion to the cubes of their fhanks. There is a ready way to find the weight of any anchor, which is to take the length of the fhank in inches, and divide the cube of that by 1160. Suppofe the fhank 10 feet long, or 120 inches; we are only to divide 1728000, the cube of 120 by 1160, the quotient 1545 will be the weight of that anchor in pounds: But if the weight were given, and the length required, we muft multiply the weight by 1160, and the cube root of the product will be the required length in inches.

As our author has given us no reafon, why we muft take 1160 for a conftant divifor, or multiplier; I fhall here endeavour to demonftrate it: But, firft obferve, that if the length of the fhank of any anchor be given, and its weight, we may then find the weight of any other anchor,

whofe

whofe length is given; and, confequently, if the weight be given, we may, by the reverfe, find the length, fince all fimilar folids are in proportion to the cubes of the fimilar fides. Now M. *Bouguer* has given us this; for he tells us an anchor of 16 feet 9 inches, that is, 201 inches, weighs 7000 pounds. Hence, we have the following general rule: Let $a = 201$ inches, the given length; $e = 7000$ the given weight, $l =$ any other length; $w =$ the required weight, then $a^3 : e :: l^3 : \dfrac{l^3 e}{a^3}$, we fhall illuftrate this by the logarithms. The queftion he propofes; is, admit the length of the fhank 10 feet, what is the weight of the anchor?

The firft thing is to find the logarithms of the lengths, and, multiplying that by 3, we have the logarithms of the cubes of the lengths.

$$a = 201 \qquad 2.303196 \times 3 \text{ is } 6.909588$$
$$l = 120 \qquad 2.079181 \times 3 \text{ is } 6.237543$$

Having thus found the logarithms of the lengths, we have the folution by the rule of three, by the logarithms.

As 201³	6.909588
Is to 7000	3.845098
So is 120³	6.237543
	10.082641
To 1489	3.173053

Now as the logarithms of the firft and fecond terms are conftant numbers, inftead of adding the firft and fecond terms, and, from the fum, fubtracting the firft; we may fubtract the difference of the firft and fecond terms, which will likewife be a conftant number, and the refult will be the fame, as by the following operation.

The firft term	6.909588	the third term	6.237543
the fecond	3.845098	difference	3.064490
difference	3.064490	the fourth term	3.173053

The reafon of this is very plain, for the fum of the fecond and third terms is .082641, now out of this we are to fubtract the firft term 6.909588; which may be done, by firft fubtracting 3.845098; and again, fubtract from that remainder, 3.064490: Since thefe two numbers make 6.909588 the firft term, which is the whole number to be fubtracted; and if we do not add the fecond term to the third, we have only the third term left, which is 6.237543; and if from this, we fubtract the conftant difference 3.064490, we in effect fubtract 6,909588, from

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10.082641, ſo the reſult muſt be the ſame, as by the common rule, and this accounts for making 1160 a conſtant number: For 3.064490, is the logarithm of 1160; which, by an error in the preſs, is in the original 3.0644580.

We may by the ſame principles, make a general rule for finding the weight of any ſhot, whoſe diameter is given; but we muſt firſt find the weight of one ſhot by a pair of ſcales. A ſhot of four inches diameter, is ſuppoſed to weigh nine pounds; therefore, as the cube of 4 is to 9, ſo is the cube of the diameter of any other ſhot to its weight.

The cube of 4 is 64; its logarithm is 1.806180; the logarithm of 9 is 0.954242; their difference is 0.851938. Hence, we have the following general rule. From the logarithm of the cube of the diameter, ſubtract the conſtant logarithm 0.851938, the remainder will be the logarithm of the weight.

Example. Let the diameter be 8 inches; required the weight?

8	0.903090	
	3	
cube	2.709270	
conſtant log.	0.851938	
required weight 72	1.857332	

This rule may be applied to gauging of ſimilar veſſels, or finding the weight of ſimilar ſolids, which will always be in proportion to the cubes of their diameters, or lengths, or any other ſimilar dimenſions.

But if the ſolids be of equal lengths, and differ only in their baſes, as is the caſe of cables; their weights will be in proportion to the areas of their baſes, or, which is the ſame thing, to the ſquares of their circumferences; as, for inſtance, if a ten inch cable weigh 20 hundred weight; what will a cable of 5 inches weigh?

As 100 the ſquare of 10	2.
Is to 25 the ſquare of 5	1.397940
So is 20 hund. wt.	1.301030
To 5 hund. wt. the required wt.	0.698970

It is upon this principle the rope table is conſtructed, which is on ſome pocket rules.

To return to our author: Theſe operations, ſays he, may be done with greater eaſe by the logarithms, only taking three times, the logarithm of the length of the ſhank in inches, and from thence, ſubtracting the conſtant logarithm of 1160, which is 3.0644580, the remainder will

will be the logarithm of the weight of the anchor in pounds; but if, on the other hand, the weight be given in pounds, we need only add the logarithm of the weight to the conftant number 3.0644580; and, dividing this fum by 3, we fhall have the logarithm of the required length.

The fmalleft fhips have five or fix anchors, and the greateft generally eight. The mariners have different rules for determining the weight of the anchors; and, on account of the conveniency of working the fhip, they have eftablifhed it as a rule, that the biggeft anchor, or, in their terms, the mafter anchor, fhould be three eighths of the beam.

Another rule, but which does not agree with the firft, as we fhall prefently fhew, is to make it weigh half rhe cable; fo a firft rate, which is 48 feet broad, and whofe cable is 24 inches circumference, weighs 13824; her mafter anchor fhould weigh 6912 pounds, and the other anchors fhould be half the weight of their refpective cables. The fmalleft anchor is the cadge, or ftream-anchor; in fhips of the firft clafs it fhould weigh 2300 pounds, and the length be about 11 feet 7 inches. When the length of the anchors is three eighths of the beam, as in large fhips, the weight of the anchor will be in proportion to the folidity of the fhips, fuppofing them to be fimilar; and, if the fhip be twice as broad, the anchor will be eight times more weight; but, according to the fecond rule, the weight of the anchor fhould be half the weight of the cable, and the weight of the cable is in proportion to the fquare of the breadth; fince it is only the circumference of the cables that differ in great and fmall fhips, the length being always 120 fathoms in all fhips. When the fhip is double the breadth, the weight of the cable will then be four times more; and of confequence the weight of the anchor, which is in proportion to that of the cable, will be half the weight it would be by the firft rule; that is, in proportion to the beam.

Although the fecond rule makes the anchors a great deal lighter, yet we may conform to it, becaufe that will be fufficient when it falls in good ground; but when the ground is foft and ouzie, the mariners make ufe of feveral expedients to fuccour the anchor; but the beft of all is, and which is chiefly practifed, to fplice feveral cables at one another's end; fo they will rub on the ground, on account of their weight; and by this means, the effort of the fhip, on the anchor, will be diminifhed.

A fhip feldom anchors in above 40 fathoms depth, and then it will be very proper to have two cables at one another's ends; for, if there is but one, the lower part of it will fcarce bear on the ground, and the anchor will be obliged to fuftain all the fhocks and jerks of the fhip, which will come quite home to the anchor; it will not pull it quite out of the ground,

ground, but drag it, in the sea term; so the ship will drive, and be in danger of being lost on the first rocks. *Fig.* 8, makes this very plain; A D is the anchor, at the bottom of the sea; D M N is the cable, by which the ship rides, of which we have here only represented the bow; N the hause-hole, thro' which the cable passes, between the two lower decks; The rope A B, fastened to the cross, or throat of the shank, is called the buoy-rope, which sometimes serves to weigh the anchor; this, in the sea term, is called, weighing it by the hour; 5 is the buoy, which serves to know where the anchor lies. It is very plain, that, if the length of the cable be doubled, or trippled, the anchor will be dragged horizontally, and with a great deal less force; for its effort will be diminished by the whole power of the friction of the part D M on the ground.

A second advantage is, that by having several cables at one another's ends, they will be less liable to breaking; for all the parts, lying more upon a level, they will oppose the shocks of the sea in a more perpendicular direction to the motions which the ship receives; whereas, when the cable is not so long, it will be nearly vertical to the anchor, and therefore cannot bear such a strain: Let the space L O represent the force with which the ship endeavours to recoil; and having compleated the rectangle L O P Q, L P, the part of the cable which is the diagonal, represents the effort which the cable should sustain, which is greater than O L; and the more it approaches to be vertical, the more it is augmented, though O L continues the same.

It is plain, then, that a shorter cable is charged with a greater effort, and should therefore be stronger, otherwise it will only bear the same strain in the proper direction, and will not be sufficient, in an horizontal direction, which is that in which the ship endeavours to drive: It is true, the horizontal effort O L is all that is to be resisted; but then the cable, being inclined, cannot resist this, without being furnished with a force sufficient to sustain the whole effort P L.

The long cable will not be so apt to break as the short one, because it will bear a great deal more stretching, before it comes to the greatest strain; so that, at the first violent tugg, because it will not bear stretching, it must infallibly break.

A long cable may be compared to a sort of spring, which may be very easily extended; and recovers its first situation, as soon as the force that extended it is removed. Besides all this, a ship will ride much smoother with a long cable than with a short one, and be less apt to plunge in the water; whereas, as the mariners have too often experienced,

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when a fhip rides with a fhort cable, fhe frequently pitches all the fore part under water.

The fourth chapter is on the power and action of oars; and, in the fifth chapter, he gives the following proportions for mafts and yards.

All fhips have generally four ftanding mafts; the firft is the main-maft, which ftands in the middle of the fhip: The fecond is the fore-maft, which is pretty near the fore end of the keel; this is nearly as long as the main-maft: The third is the bowfprit, which, inftead of ftanding upright, ftives forward, and refts on the head of the ftem: The fourth is the mizen-maft; but fome fmall fhips have not this maft; it ftands abaft, towards the poop. Befides thefe, the main and fore mafts have top and top-gallant mafts, and the mizen-maft a topmaft. All thefe mafts have their particular fails, and are named according to their refpective mafts.

The main-maft is placed in the middle of the fhip, meafured from the head of the ftem to that of the poft, or its whole diameter abaft the middle of the fhip: All the builders agree in this, but they differ widely as to the reft; fome place the fore-maft precifely at the fore end of the keel; others again take the 40th or 50th part of the whole length, from the ftern, for its place; and fome will have it ftand on the ftem. The bowfprit generally ftives, fo as to make an angle of 35 degrees with an horizontal line. Laftly, the mizen-maft is about three fixteenths of the length of the whole fhip, before the head of the ftern poft: If the fhip be 160 feet long, the mizen-maft is 30 feet before the ftern poft.

In *France*, the main-maft is generally, in length, twice the breadth and half the breadth of the fhip; whereas, the *Englifh* make it only twice the breadth and two fifth parts of the breadth; fo, fuppofing the fhip to be 40 feet broad, the *French* builders would make the main-maft 100 feet long, whereas the *Englifh* make it only 96.

The *Dutch* make their mafts fomewhat longer than ours, though they agree with all other nations in regulating the lengths of their mafts by the breadth of the fhip. The head of the maft is always the tenth part of the length of the maft.

The diameter of the main-maft, at the partners, is as many inches as three fourths of the extreme breadth is feet; fo, if the extreme breadth be 40 feet, the main-maft will be 100, and the diameter, at the partners, 30 feet, that being three fourths of 40; or, which is the fame thing, the 40th part of the whole length of a fhip fuppofed to be 160 feet: The diameter at the head is generally allowed to be two thirds of that at the partners, which will make it 20 inches.

I muft own, fays our author, it is with violence to myfelf that I
am

am obliged to give a detail of all thefe rules, which have not the leaft foundation in reafon, and are proper only to be confuted.

The fore-maft is in length twice the breadth and one quarter more ; and its diameter, as well as that of the other lower mafts, is about the 39th part of the whole length ; others make it nine tenths of the length of the main-maft.

The length of the bowfprit, is the breadth and half breadth of the fhip, and its diameter the twenty-feventh part of its length ; fo if a fhip be 40 feet broad, the bowfprit will be 60 feet long, and $26\frac{2}{7}$ inches dia-. meter at the bed, and at the cape it will be half what it is at the bed.

Laftly, the mizen-maft is, in length, the breadth and three quarters of the breadth of the fhip ; and its diameter, at the partners, as many inches as feven fixteenth parts of the main breadth is feet, or rather, the forty-eighth part of its length.

Proportions for Top-mafts.

The maintop-maft, in length, is the breadth and half breadth of the fhip, which makes it equal to the bowfprit ; the diameter at the cape is about the forty-third part of its length.

The foretop-maft, in length, the breadth and three eights of the breadth ; the diameter, at the cape, the forty-third part of the length.

The mizen-top-maft is half the length of the main-top-maft ; and its diameter, at the cape, half the diameter of the main-top-maft.

The main topgallant-maft is five twelfths of the length of the main-top-maft ; and it is half the diameter.

The fore top-gallant-maft is four fevenths of the length of the fore-top-maft.

The fpritfail topmaft is, in length, two fifths of the main breadth ; and its diameter generally as many inches as there are feet in feven thirty-fix parts of the breadth ; that is, fomewhat lefs than the twenty-fifth part of the whole length.

Proportions for Yards.

The main-yard, in length, is twice and one fixth part of the main breadth ; the diameter, at the flings, one inch to every foot in two thirds of the main breadth ; or, which is the fame thing, the thirty-ninth part of the whole length : The yards are of a quite different figure from the mafts ; they taper from the flings towards the yard-arms ; the diameter, at the end, is one third of that at the flings.

The main-top-fail yard, in length, is the main breadth and quarter of the breadth ; the diameter, at the flings, half that of the main yard,

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The main-top-gallant yard, in length, is three quarters of the main breadth ; and the diameter, at the flings, half of that of the main top-fail yard.

The fore yard, in length, is exactly twice the main breadth of the ship ; its diameter, at the flings, one inch to every foot in five eights of the breadth.

The fore-top-fail yard is, in length, the breadth and fixth part ; and its diameter feven fifteenths of that of the fore yard.

The fore-top-gallant yard is, in length, two thirds of the breadth ; and its diameter half that of the fore-top-fail yard.

The fprit-fail yard, in length, is the breadth and one quarter ; and its diameter, at the flings, one inch for every foot in the third part of the breadth, which will be half the diameter of the main yard.

The fprit-fail top-fail yard, in length, is three quarters of the breadth ; and its diameter feven fixteenth parts of that of the fprit-fail yard.

The mizen yard is inclined, on account of the triangular form of the fail, and is the hypothenufe of a right angled triangle ; it is, in length, twice the breadth of the fhip, and its diameter one inch to every foot, in one third of the breadth ; at the lower arm it is two thirds, and at the upper arm one third of the flings.

The mizen top-maft is, in length, three fourths of the breadth ; and its diameter, half that of the mizen yard.

Of the proper Figure of Mafts and Yards.

Our readers, fays our author, know very well that the mafts, as well as the yards, are round, like cylinders, or cones ; but, perhaps, they imagine the fides are ftrait.

The beft maft-makers make the fides of their mafts curves, which form an arch of an ellipfe. Our author here fhews us how they form thefe curves ; for which we refer to *Chap.* VII. *Sect.* I. *pag.* 106. of the foregoing Treatife ; and proceed to the 6th chapter, where he makes fome remarks and experiments on the before-mentioned proportions.

It is eafy to judge, that the dimenfions of the fails are regulated by that of the mafts and yards.

The main-maft, of itfelf, is 120 feet ; the main-top-maft 72, and the main-top-gallant maft 30 feet , a monftrous height, when all thefe are on end ; and they are proportionally fo in leffer fhips : If the mariners would but attend to what they fee every day before their eyes, they would eafily be convinced, that it would be a great advantage to fhorten them prodigioufly ; and, if they pleafe, make the yards longer, to gain what they

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lose in the height of the masts. A small sail, when very high, will have more power to make a ship heel than to go a-head; because, being placed at the end of a long lever, it is removed at a great distance from the center of gravity; and whereas a larger sail, when placed low, has less power to heel the ship; yet it does not hinder it from exerting all its effort in respect of sailing. All that the mariners have to plead for this rule is, that experience, and the universal consent of all nations, are on their side; but we can assure them, experience, instead of favouring them, makes quite against them. There are daily instances of ships being dismasted at sea; and when they have got up jury-masts, have sailed as fast as with the proper masts; on the contrary, when they give a ship taunter-masts, she will not sail so fast as before; an instance of this happened some years ago in his majesty's ship the *Content*, which they masted beyond the common rules; or, perhaps, only observed them to the utmost rigour, and immediately she lost a great part of these advantages; a certain mark that the masts are too high.

We perfectly agree, with our author, that when ships are dismasted in a very hard gale of wind, and the sea running very high, they will sail better with jury than with their proper masts, even when the top-gallant masts are struck, and all their sails handed; but when the storm abates, and becomes moderate, so that a ship can carry top-gallant sails, it is presumed she would soon run another ship, with jury masts, out of sight.

But the height of the masts, says our author, is not the only fault that attends these rules; there is another secret evil which they carry in their bosom; they do not conform to the laws that should be observed in ships of different dimensions. If one ship is twice as long, and twice as broad, they make the sails of this last double the dimensions of the first; but, as all ships are allowed to heel, a small ship should have a great deal less sail, in proportion, than a great ship: Supposing one ship half the dimensions of another, the small ship will only be the eighth part of the solidity, and the eighth part of the weight of the great one; and, as it is the weight that opposes the wind, when it makes its effort to overset, or at least to heel the ship, she will have but the eighth part of the absolute force which is necessary to sustain the sail; but this same force, which is diminished to one eighth part, is collected in the center of gravity, and applied with double disadvantage. Seeing all the dimensions are less by one half, the center of gravity will be but half the distance below the decks, or load-water line; so the relative force, by which the weight of the ship opposes the effort of the wind, is only the sixteenth part of what the large ship has. In order to judge if these rules be good or bad, we have
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only to examine if the relative force, which the wind has to overfet a
fmall fhip, be likewife diminifhed to a fixteenth part ; and, if they agree,
the equilibrium will not be deftroyed. This will be a mark that the rules
are perfect, and we may continue to make the mafts proportionate to the
other dimenfions of fhips.

But when the dimenfions of the fails of fmaller fhips are half the di-
menfions of the large, the furface of the fails is only diminifhed one quar-
ter : It is true, the center of that effort is but half the height above the
fhip, and, of confequence, applied to the lever of only half the length ; But,
when all is confidered, the relative force which tends to overfet, is only
diminifhed to one eighth part ; whereas the other is diminifhed a fix-
teenth part, as we have juft now proved. It is plain then, that the force
of the wind will predominate, being two-fold too great ; fo that if the
great fhip be properly mafted, the fmall one cannot be fo likewife, but
will be in danger of overfetting.

To fpeak in more general terms, the relative force with which the
fhip oppofes the effort of the wind, is diminifhed in proportion to the
fquare of the fquare of the keel, or of the breadth and the weight ; or the
abfolute force is diminifhed in proportion to the cubes. But the relative
effort of the wind is not diminifhed, but as the cube of the keel, or as
the cube of the breadth ; fince the abfolute force of the wind, which is
proportioned to the furface of the fails, is diminifhed but as the fquare ;
and that the height of the maft, which ferves as a lever to that force,
diminifhes only in proportion to the keel, or to the breadth ; fo, in fmall
fhips, the force which they have to fuftain the preffure of the fails is al-
ways diminifhed, in a greater proportion, than the relative force of the
wind to overfet them ; and, of confequence, if there be an equilibrium
betwixt thefe two forces in large fhips, it cannot fubfift in fmall, the firft
being too little, and the force of the wind too great. It follows then,
that the common rules are defective, and will be at leaft fubject to one
of thefe two inconveniencies ; for the fmall fhips, being over-mafted,
will not be able to carry fail with fafety ; and, on the contrary, the great
fhips, for want of fufficient mafts, will lofe the advantages the taunt mafts
would procure.

The common rules being thus found defective, we cannot fubftitute
others fo fimple in their room ; but, if we had but one fhip properly
mafted, we might, by that, regulate all the mafts of fimilar, or nearly fi-
milar fhips. The relative force which fhips have to fuftain the preffure
of the fails, is as the fquare of the fquare of their fimple dimenfions ;
and the relative force, which the mafts have to overfet, is as the breadth

of

of the fails multiplied by the fquare of their height; fince this height augments the extent of the fails, and at the fame time makes the center of their effort higher: On the other hand, we can fcarce difpenfe with regulating the breadth of the fails by that of the fhip; we may make them more or lefs, but they fhould always depend on one another. So, fince the relative force of the fhip, to fuftain the preffure of the fails, is as the fquare of the fquare of the breadth, the relative force which the fails have to make her heel is as the product of that fame breadth, by the fquare of the height of the maft: But if there be an equilibrium betwixt thefe two forces, there will be an equality of ratios betwixt the two quantities that exprefs them; and this equality will fubfift if the two quantities divided by the breadth. Hence it follows, that, to have two fimilar fhips properly mafted, the fquares of the heights of their mafts muft be as the cubes of their breadths, or of their lengths. This theorem may ferve as a rule; and it will always be eafy to determine the dimenfions of the mafts of any fhip, provided we have another properly mafted, which may ferve as a ftandard.

It feems there can be no inconvenience in regulating all mafts by thofe of the third clafs. In a fhip of the third clafs, which is 137 feet long, the fails on the main-maft are generally about 118 feet high. In order then to find the height of the fails of a fimilar fhip, which is 83 feet long, we have only to make this fimple proportion: As the cube of 137 is to the fquare of 118, fo is the cube of 83 to the fquare of the height of the fails, on the main-maft of the fecond fhip; this fquare is 3096; and, of confequence, the required height of the maft is about $55\frac{1}{4}$ feet; which, by the common rules, would be $71\frac{1}{2}$ feet. Tho' this operation is not long, it may be fhortened by the logarithms.

But if the fecond fhip is not fimilar to the firft; if fhe be either broader or narrower, deeper or fhallower, the mafts muft undergo a fecond change in proportion to the breadth; that is, if the fhip, which is 83 feet long, inftead of 23 feet broad, according to the common rules, be only $15\frac{1}{3}$, or two thirds of 23, the height of the maft muft be only $37\frac{1}{15}$, inftead of $55\frac{1}{4}$. It is eafy to remark, that the fhip being the fame length, but a confiderable change in the breadth and depth, the height of the mafts muft receive a proportionable change.

For, fuppofing that the breadth of the fails is regulated by that of the fhip, and that the height of the maft is likewife changed in proportion to the fame breadth of the fhip, the extent of the fails, and, in confequence, the abfolute impulfion of the wind, will be in proportion to the fquare of that breadth, and its relative force in proportion to its cube; at the fame tim

time that the relative force with which the weight of the ſhip reſiſts the inclination, is proportioned to the ſame cube, and not to the ſquare of the ſquare, ſince the length of the ſhip is ſuppoſed ſtill the ſame; for it follows from thence, that the alterations made in the ſails, anſwer exactly to thoſe made in the breadth of the ſhip, and that the equilibrium is no ways altered. If the breadth be doubled the ſails will be doubled, both in breadth and depth; ſo the ſurface will be quadrupled; and, when the height of the center of gravity is likewiſe doubled, its force will be eight times greater; but if the relative force of the wind, to overſet the ſhip, be eight times greater; on the other hand, the weight of the ſhip which oppoſes that has eight times greater force, and then we ſhall have nothing to fear. The ſhip in effect has the ſame number of vertical ſections perpendicular to the keel, which are the elements of the ſolidity, but each will be quadrupled, and the quadrupled weight of the ſhip, being ſituated twice as low, or with double advantage, ſince the depth is likewiſe doubled, will have eight times the force preciſely, as is neceſſary always to retain an equilibrium with the effort of the wind. We now perceive the propriety of joining this ſecond rule with the former, which every one may eaſily do, who has one ſhip properly maſted, by which to determine the dimenſions of the maſts of all other ſhips, even of thoſe which are not ſimilar, provided the vertical ſections of the immerged part be ſimilar.

The firſt rule is, that the ſquares of the heights ſhould be as the cubes of the ſimple dimenſions.

The ſecond is, that the heights of the maſts ſhould be proportionate to the breadth of the ſhips, provided they be the ſame length.

Theſe two rules being admitted, we may uſe the beſt we can pick out of the common rules, and examine the heights of the maſts of each ſhip, as if ſimilar to thoſe of the third claſs, as they build them at this time; and then we need only enlarge, or diminiſh, the ſails, and the heights of the maſts, already found, according as the ſhip is great, or ſmall.

We may find other rules, which tend to the ſame end with the preceding. As for example, a third is, that in ſhips of the ſame breadth, but of different lengths, the heights of the maſts ſhould be as the ſquare roots of the lengths; for the relative force which theſe ſhips have to ſuſtain the preſſure of the ſails, or to oppoſe the inclination, is proportionate to their lengths; ſeeing the other dimenſions are no ways altered. The center of gravity is neither raiſed, or lowered; it is only the whole weight that is greater or leſs, according to the length; and the relative force will

always

always be in the fame proportion : But when the breadth of the fhip con-
tinues the fame, that of the fails will likewife be the fame ; and the re-
lative force they have to make the fhip heel, depends wholly on their
height, but that is two ways : The firft is, becaufe the height of
the maft will increafe the furface of the fail expofed to the wind ; the
fecond is, becaufe the center of effort is raifed, or the lever is longer ; fo
the relative force of the fails increafes the fquare of their heights, and in
cafe of an equilibrium, that fquare muft be proportionate to the length of the
fhip, which expreffes the other relative force : And of confequence, the
heights of the mafts and fails fhould be proportionate to the fquare root
of the length. Suppofing that, without altering the breadth and depth,
we fhould make the fhip four or nine times longer ; we need only, ac-
cording to that rule, double or triple the heights of the mafts. Laftly,
if we add this third to the fecond above mentioned ; namely, that in fhips
of the fame length, but of different breadths, the heights of the mafts
fhould be proportionate to the breadth, we may from thence deduce the
following fourth theorem.

In fhips of different lengths and breadths, the heights of the mafts
fhould be in a compound proportion of the breadth and of the fquare
root of the length, or they fhould be as the products of their breadths, by
the fquare roots of their lengths.

Such of our readers, continues our author, as are not well verfed in
geometry, may eafily be convinced of the truth of the moft part of what
has been faid on this head, by trying experiments. If the heights of the
mafts fhould have the fame proportion in all fhips, it muft hold in the
fmalleft as well as in the largeft ; and, on the contrary, if thofe rules are
erroneous, the true way to difcover the fault will be, to maft an enormous
large fhip by thefe rules, and likewife a very fmall one ; perhaps one or
two feet long ; this will be, as the faying is, hitting the nail on the head.
We may by this way bring the rule to fuch a proof, as may be deemed
the true touch ftone. When I was at *Havre de Grace*, continues our
author, and ruminating on thefe things, I caufed two fmall fhips to be made
perfectly equal ; and of the fame form with the *Gazele* frigate, building
at that time for the king. My two fmall fhips were each about 18 or 20
inches long, I cannot be pofitive to the exact length ; but this I may
venture to affert, that they were exactly fimilar to the frigate, and one of
them mafted according to the eftablifhed rules. I took upon me to maft
the other, which I did not to the utmoft perfection, that I might depart
as little as poffible from the common rules. In fhort, we gave the two
fhips the fame loading and ballaft, we carried them to a piece of water of
fufficient

fufficient extent for our purpofe, where they were expofed to the whole force of the wind, which then blew pretty hard; the experiment was fcarce begun, when that mafted in all refpects fimilar to the *Gazele*, over-fet topfy-turvy a hundred times, to the great aftonifhment of all the fpectators: Not confidering that although all the parts could be made proportionate to thofe of the frigate, but 50 or 60 times lefs than the cor-refponding parts of the frigate, yet they could not at all abate the fury or force of the wind, and by this means they expofed the little fhip to a perfect ftorm fo furious, that the greateft fhip could never encounter. It is granted, continues M. *Bouguer*, that the fails of the fmall fhips are 60 times lefs than thofe of the frigate; and therefore the impulfion they receive, will be 3600 times lefs than thofe received by the frigate, al-lowing the wind to blow with the fame force, and the effort of the wind to overfet the fhip, will be 216,000 times lefs. But the force which the weight of the fmall fhip has to recover or right herfelf, is likewife 60 times lefs, for the weight itfelf is become 216,000 lefs, and when applied to a lever, 60 times fhorter, it fhould have 1,296,0000 lefs relative force. After this, it is no ways furprifing, that the fmall fhip which has 60 times lefs force, in proportion to the *Gazele*, to fuftain the preffure of the fails, fhould not for one moment refift the effort of the wind, not even when great part of the fails are furled; and feveral other expedients tryed by many who intereft themfelves too much to preferve thefe proportions, and fave, if poffible, the credit of the common rules. I fairly own that the model I made overfet likewife feveral times; becaufe, as I obferved before, I fatisfied myfelf in making the dimenfions of the mafts, nearer to the true, only in retrenching fimply the principal defects in the com-mon eftablifhment; and the wind at the fame time blew in heavy fqualls, but the other fmall fhip, after they had reeft part of their fails, overfet 20 or 30 times to one of mine, which is a plain proof that the mafts, fhould not be proportionate to the other parts of the fhip.

In the feventh chapter, he treats of the names and ufes of the ropes, which conftitutes the ftanding andrunning rigging; which concludes the fecond fection.

In the third fection, he treats of the abfolute relative force of folids, whether wood, iron, or any other metal ufed in fhipping, and endeavours from thence to make a general rule, for determining the fcantlings at every particular piece of timber in a fhip: He alfo confiders, whether the common methods are fufficient for preventing a fhip's hogging or cam-bring; this takes up four chapters; but as M. *Duhamel* has given us a

<div align="right">table</div>

table of fcantlings and dimenfions, we refer our readers to the Appendix for determining that point.

In the fifth chapter, he gives us the following account of the folid of leaft refiftance ; that is, fuch as is not liable to be broke in one part more than in another.

Seeing it is certain, that in all bodies whofe elementary flices form fimilar figures, the relative refiftances are in proportion to the cubes of the diameters of their thicknefs, we may from that principle determine the figure of the folid of leaft refiftance, that is fuch as is not liable to be broke in one place more than in another.

Suppofe a power applied to the top A of the body A B, *Fig.* 9, and acts at the upper end in the direction A G, perpendicular to the axis of the folid, of which all the elementary flices are fuppofed to be either fquares, or cylinders ; this power will have more or lefs relative force to break the body according to its diftance from that part which bears the greateft ftrain. If that part be near to the top, the relative force of the power acting on A will be weak, but ftronger when at a greater diftance ; it will always be proportionate to that part of the axis A C, which ferves as a lever to the power : Now the relative refiftance of folids, which are as the cubes of their diameters, fhould be equal to the relative efforts of the power that preferves the equilibrium ; fo the cubes of the diameters at different parts of the lengths, fhould be in proportion to the lengths of the parts of the axis ; confequently the folid of equal refiftance in all its parts, fhould be a conoid formed by the firft cubick parabola. A power at eight times the diftance will have eight times the effort to break the folid, on which account the diameter at that place muft be double that which is at the top, where the power is fuppofed to act. If the power is 27 times the diftance, it will have 27 times more purchafe ; but if the diameter at that place be three times bigger, it will be able to fuftain that whole weight.

We need not obferve that this fhould be the figure of mafts ; it will be proper here to fhew how this cubick parabola may be defcribed, which may be done by the following method, delivered to us by our author.

Divide the length into 64 equal parts, and the diameter at the partners, into four equal parts. In order to determine the diameters at thefe feveral parts of the length ; at 27 parts of the length, the diameter is three fourths of that at the partners ; at 8 of the length of the diameter, half that at the partners, and at the firft divifion of the length, the diameter one fourth of that at the heel.

Note,

Note. The parts of the length are accounted from the top, and in order to find the intermediate points betwixt thefe, fee the following table.

Parts of the length.	Diam.	Parts of the length.	Diam.	Parts of the length.	Diam.	Parts of the length.	Diam.
60	3.91	45	3.56	30	3.11	15	2.47
55	3.8	40	3.42	25	2.92	10	2.15
50	3.68	35	3.27	20	2.71	5	1.71

In regard to the yards, they fhould not have the fame figure, they fhould terminate in a point at each end, and each half fhould be formed by the revolution of a fecond cubick parabola. It is eafy to perceive the reafon of this difference; that power which tends to break the yards is not only applied at a lefs diftance towards the extremities, but is alfo lefs, becaufe the effort of the fails being diftributed the whole length of the yard, there will be only that force which exerts itfelf on each part of the yard. The whole effort which the maft fhould fuftain, is applied at the top, fo it is always the fame abfolute force which tends to break the maft; whereas in the yards, the abfolute force is greater towards the middle: The middle of the yard has not only the greateft effort to fuftain, but this force is likewife applied at a greater diftance. If we examine the effort of the fail at one quarter of the length of the yard, we fhall find it but one half of that which it is at the middle, and, befides, the center of its effort is applied but at one half of the diftance. In one word, the relative forces which tend to break the yards are, as the fquare of their diftances from the next yard arm, and as the refiftance fhould be in an equilibrium with thefe forces, it muft follow that the cubes of the diameters be in proportion to the fquares of the diftances from the yard arm. Hence, if we divide half the length of the yard into 64 equal parts, and the diameter at the flings into 16, the diameter at 27 parts of the length accounted from the yard arm, muft be nine fixteenths of that of the flings; at 8 parts of the length, the diameter muft be one quarter of that at the flings, and at one fixty-fourth of the length, the diameter muft be one fixteenth of that at the flings.

Our author, then confiders the mafts that fhould be made of feveral pieces, being too large for to be made of one tree, and thinks they fhould be of a different form; at the fame time, he tells us, the mariners do not conform to any of thefe proportions; and that they are as much deceived, in refpect of the figure, as in the length; though, they are very fenfible, the figure of mafts fhould differ from that of the yards. The builders, however, fays he, have found to as great perfection as poffible the pro-

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portions the diameters should bear to the other dimensions; for when they discovered the weakest part, they have made them bigger at that place, and, by the mere dint of repeated trials, have brought that point to as great perfection as could have been done, by the assistance of geometry.

In the sixth and seventh chapters, he considers the strength of the cordage, which concludes the first book.

In the second Book, he considers the ship when a float, and at rest.

In the first section, which he divides into six chapters, he treats of the weight of a ship, and the force of the water to sustain that weight.

The first three chapters are chiefly employed in prescribing rules to ascertain the precise draught of water a ship should draw, when properly loaded; which he performs by measuring the immerged part, and thereby discovers if her load-water line corresponds to that in the draught; the substance of which M. *Duhamel* has extracted, for which we refer to the Abridgment, Chapter VIII.

The other three chapters are wholly taken up in gauging of ships, and determining their tonnage, either in weight or bulk, and regulating the fees for anchorage, and other duties, which are regulated by the tonnage.

This concludes the first section; and, in the second, he treats of the weight of the ship, and the proper position of the center of gravity, and gives rules for finding it. This with his remarks, takes up ten chapters, which M. *Duhamel* has given us in his second edition, the translation of which is hereto annexed, to which we refer; but we must not pass over what M. *Bouguer*, says of the mechanick way of finding the center of gravity.

All the mechanicks, says he, know how to find the center of gravity of any body by suspending it. It is worthy to be remarked, continues our author, that this method may be very useful, and easily executed in the naval arsenals, where they have ready prepared every thing, that is necessary for that purpose: All that is required is only to make a block of wood exactly similar to the immerged part of the ship, and proportioning all the parts of the block to the corresponding parts of the ship, by a scale of one fourth or one third of an inch, or any other convenient space, to one foot of the corresponding parts of the ship; care must be taken to have the wood as light as possible. The block being thus prepared, may be suspended by a piece of packthread, in different situations; if we conceive the packthread produced, it will point out the center of gravity. Notwithstanding the simplicity of this practice, our author says, it will be

convenient

convenient on some occasions to use other methods, which may be more directly applied towards finding the center of gravity.—Thus far our author.

We shall here add, that some useful discoveries may be made by models, or blocks, and this, we conceive, with as great certainty as by calculation; for it must be allowed by the nicest calculators, that the *data* taken from the draught of a quarter scale, may be liable to great errors; but, upon strict examination, we may venture to assert, that there are very few ships that have both their sides exactly equal in every respect, and there need be no more convincing proof of this, than suspending the block by a piece of pack-thread fastened to a hook in any part of a strait line, drawn from the middle line of the stem to that of the post. This hook may be moved forward and aft to different places in the middle line, and a plumet suspended from the upper part of the midline of the stem, and another from the] upper part of the middle line of the post, if the two sides be exactly of equal dimensions, and likewise homogene, they will be of equal weight: A plane passing through these three lines, whatever part of the middle line the hook be in will likewise pass through the middle line of the keel, stem, and post; a block that will stand this proof may be truly said to be a most valuable piece of workmanship, executed to the greatest possible perfection, and may be deemed the master-piece of the art, and must redound to the great honour of the workman.

The block being thus provided, and suspended by the hook, the plumb-lines at the stem and post at the same time corresponding to their middle-lines, and to that which suspends the block, we may hold a batten out of winding, a term well known to the shipwrights, with the line that suspends the block, and with a pencil draw a line on the block; a plane passing through this pencil line, at right angles to the keel, and passing likewise through the line that suspends the block, will likewise pass through the center of gravity, which, therefore, must be somewhere in this plane; again, move the hook to some other part in the middle line, and let the block be suspended from that point; draw also another pencil line out of winding, with this last line of suspension : The intersection of the two pencil lines will give the height of the center of gravity above the keel, and likewise its distance from the post and stem; and if the hook be moved to any other parts in the midline, and a pencil line drawn as before, it will likewise intersect in the same point, or let there be never so many points assumed in the middle line, and the block suspended by each, and pencil lines drawn, they will all intersect in the same point, and as the center of gravity will always be in that plane which passes

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through

through the middle line of the keel, ftem, and poft, it may, with certainty, be marked on the draught.

It muft be allowed this will require the utmoft nicety, and, if well executed, will agree exactly with that found by calculation, provided the dimenfions be taken with an exceeding good fcale of equal parts, for which we judge the diagonal fcale of equal parts in Plate II. of the foregoing Treatife to be fufficient.

Having thus found the center of gravity of the immerged part, we may, by the like procefs, find the center of gravity of the whole fhip, compleatly rigged, mafted, and with all her guns, ammunition, provifions, &c. on board. In order to which the model muft be compleated, her upper works, &c. fimilar to the fhip, mafted, rigged, and have the fame number of guns, fhot, cafks, caft ballaft, in fhort, every particular fpecies that compofe the whole weight of the fhip, all fimilar to the refpective fpecies in the fhip, that is, in proportion to the cubes of their fimilar dimenfions. All thefe things being ftowed in the model, they may be fhifted fore and aft, higher and lower, till fuch time as by repeated trials the center of gravity of the whole fhip may be properly fituated with refpect of that of the immerged part.

It muft be allowed this will require the utmoft care in the execution, but it muft likewife be allowed, it will require no lefs care and accuracy to find the exact dimenfions of the feveral fections of the fhip, efpecially as every dimenfion in the fhip is 48 times bigger than their fimilar ones in the draught, fo that an error of a quarter of an inch in the draught, which is only the 48th part of a real inch in the fhip, will occafion an error of 110592 cubick quarters of an inch in the fhip, provided the error be in all the three dimenfions, viz. length, breadth, and thicknefs.

There are feveral models compleately mafted, rigged, with guns, anchors, &c. proportioned to thofe of the fhip; fuch as have thefe in poffeffion may make feveral ufeful experiments in water; a few of which we fhall mention.

Firft, to find the whole weight of a fhip when properly loaded to the propofed water-line.

To attain this, let the loadwater line be drawn with a pencil on the model, and loaded till that line come exactly to the water's edge, after which take the model out of the water, and let it be fufpended till all the water drains off, and then weighed. The following proportion will give the weight of the fhip; 1 is to the weight of the block, as the cube of 48 is to the weight of the fhip. Note, this may be done without the mafts, and the block may be loaded with fand, or any other

ponde-

ponderous body, that will fink the model to any propofed draught of water. If the weight of the fhip be given, we may find what the weight of the block fhould be by the reverfe of this proportion. We fhall illuftrate this by an example.

Example. Admit a model, when properly loaded, weighs 163 ounces, what will be the weight of the fhip in tons?

As 1	0.
Is to 48^3	5.043723
So is 163	2.212188
	7.255911
Subtract	4.554368
Tuns 503	2.701543

As the index of this logarithm is 7, the natural number muft confift of eight places, and the anfwer will be in ounces, which cannot be had in the common tables. We fhall therefore reduce them to tons by the common rules of reduction. Firft divide the ounces by 16, gives pounds; divide the pounds by 112, gives hundreds; laftly, divide the hundreds by 20, and we have the anfwer in tons. Now all this may be done by fubtracting the fum of the logarithms of thefe three divifors from the fum of the logarithms of the firft and fecond term, as in the preceding operation.

16	1.204120
112	2.049218
20	1.301030
Sum	4.554368

Hence we have the following general rule : To the logarithm of the weight in ounces, add the conftant logarithm of 48^3, which is 5.043723, and from the fum fubtract the conftant logarithm 4.554368; the remainder will be the logarithm of the number of tons. It muft be obferved, that if the fcale be not a quarter of an inch to a foot, we muft not take the logarithm of 48^3, we muft find how many of the parts that reprefents one foot in the draught will make a real foot; as for inftance, if the draught be a three eighth fcale, it will take 32 of them to one foot, fo that in that cafe we muft take the logarithm of 32^3; if by a half inch fcale, the logarithm of 24^3; if by a three quarters, the logarithm of 16^3, &c.

Secondly, we may, by the fame rule, find the weight of the fhip when launched : It is only loading the block to the fame draught of water with the fhip when launched, and then taking the weight in ounces,

and

and use the same process as before; we may repeat the same when ballasted, when rigged, in short, we may find the weight of the masts, guns, provisions, &c. or how much weight will be necessary to be put on board to make her draw an inch more water. It must be understood that this rule will give the tons, in the common acceptation of that word; for by that is meant the builders tons; for finding which there is an established rule, which may vary according to the custom of the place she is built in. The freight of goods in the merchant service is either in weight, or bulk; the weight is 20 cwt. to one ton, and 40 cubick feet make one ton.

The general rule for determining the tonnage of ships taken into his Majesty's service.

1. Let fall a perpendicular from the back of the main post at the height of the wing transom, to the rabit of the keel produced.

2. Set forward for that two inches and a half for every foot in height for the rake of the post, and from that point measure to the perpendicular let fall from the foreside of the stem, observing, if the ship is not on an even keel, to make use of a square applied to the base board.

3. Deduct three fifths of the extreme breadth out of that length, the remainder is accounted the length of the keel for tonnage.

4. Multiply this length by the extreme breadth, and this product by the half breadth; divide this product by 94, the quotient will give the required tons; or, which is the same thing, multiply the length of the keel by the square of the breadth, and divide the product by 188; the quotient will give the tons.

Example. Keel for tonnage 144.5 feet; breadth extreme 51; required the tons? The following is the operation performed by logarithms:

51²	3.415140
144.5	2.159868
	5.575008
188	2.274158
1999 tons	3.300850

(See this operation performed by the sliding rule, p. 99 of the foregoing Treatise.)

In the merchant service take the depth of the keel below the rabit, and set that off from the rabit of the post, then proceed as before; for boats, in general, proceed from the back of the post, and proceed as above.

It is the general practice of the builders to measure the tonnage by the real dimensions of the ship, when upon the blocks. The builders and mariners agree in this point, and experience proves beyond dispute, that

few,

few, if any ships, are exactly similar to the draughts; and, indeed, it is impossible they should, unless the thickness of the plank be laid down in the draught, which, perhaps, may be one of the most intricate operations in the practical part of ship-building; however, I shall attempt it in another place. The chief design of laying down the proposed dimensions on paper, and then in the loft, is to determine the exact form and bevelling of every timber in the ship, which is now done to so great perfection in his Majesty's dock-yards, that they want very little reconciling when going to be planked. As there is scarcely a possibility of ascertaining the true dimensions from a draught, it seems there can be no great dependance on the calculations mentioned by our author. He has, to his great honour, carried his investigations to the utmost nicety; having considered the minutest circumstances, and the alterations the ship undergoes in all different situations, and has brought the theory of ship-building to as great perfection as the nature of the subject will permit, though very few shipwrights can follow him in his deep researches.

Our author, in the eleventh chapter, shews how to find, by a simple experiment if the center of gravity of a ship be properly situated, even after she is built.

It would, says he, undoubtedly be of great advantage, after a ship is built, rigged, and loaded, to have it in our power to be well assured, even when she is in the harbour, that the center of gravity be properly situated with respect to the metacenter.

Sometimes there are many things ranged and placed in a very different manner. The consumption of ammunition and provisions in a long voyage is very considerable, and it will be necessary to know what changes result from thence; and this is what may be had by a very simple experiment. We are obliged for the first idea of this to Father *Hoste*.

If we place a weight P, on the outside of the ship O E C, *Fig.* 10, at the outer end Q of a sparr, laid across the ship, this will make the ship incline to a certain point, at which time there will be an exact equilibrium betwixt the weight suspended without the ship, and the whole weight of the ship, on each side of the line Y Z, in the direction of the vertical effort of the water. The common center of gravity G, is in the same vertical with the metacenter, when the ship is in an horizontal situation; by the metacenter our author understands that point, above which the center of gravity should never be placed. The more the ship inclines, the further will the center of gravity G be removed from the line Y Z, the vertical of the metacenter, and it is plain that G T, the distance from that line, is always in proportion to the sine of the

the inclination; at leaft, when the inclination is but fmall. Now if that diftance, and likewife the whole weight of the fhip be known, we have likewife its moment, or the relative force with which that weight acts, in endeavouring to right the fhip, and bring her again into an horizontal fituation; but fince both the fituation, and likewife the weight that produces the inclination are known, we may from thence know if the moment of one be equal to that of the other, and thereby eafily difcover if the center of gravity be in that very point we propofe.

We cannot be too nice in taking the quantity of the angle of inclination, for the fuccefs of the whole experiment depends on this: To attain this, we may ufe a level line for the fenfible horizon of the fea, or a plumb-line faftened to the head of the maft, and take its diftance from the foot of the maft, both when the fhip is upright, and likewife when fhe heels; the plumb-line feems to be the moft convenient, becaufe we have thereby immediately the proportion in which the center of gravity recedes from the vertical of the metacenter, which will always be in proportion to the diftance of the plumb-line from the foot of the maft. We muft be very careful, during the whole time of the operation, to render all the circumftances abfolutely the fame, that we may be well affured the inclination is produced only by the weight applied to the outfide of the fhip : No doubt, this will require the affiftance of many hands, to put every thing requifite in its proper place, but they muft all withdraw, when the diftance of the plumb-line and the other dimenfions are meafuring. The weight of two or three, or fometimes even ten men, need not be regarded; whereas the weight of the whole crew would produce a very fenfible alteration; and, I conceive, the crew might be difpofed to great advantage in this experiment, as they may be eafily moved from one place to another.

We may, by this means, find the center of gravity of the fhip, provided we know only the metacenter; for, having the quantity of the weight that produces the inclination, and examining R Z, its diftance from the metacenter, or from the vertical that paffes through that point, and on which the effort of the water exerts itfelf, we have likewife its moment, or its relative force, which is equal to that of the weight of the whole fhip, fince thefe two exactly ballance one another; fo it is only dividing this moment by the whole weight of the fhip, and the quotient will give us the diftance of the center of gravity, G, from Y Z, the vertical of the metacenter. If the weight that makes the fhip incline be 5 tons, and its diftance from Y Z be 30 feet, its moment will be expreffed by 150; and if this moment is divided by 1800, which is fuppofed to

be

be the whole weight of the ſhip, we ſhall find that the diſtance of the center of gravity is from the vertical, Y Z, one inch. After this, it will be eaſy to diſcover how far the center of gravity is below the meta-center g; ſince there will always be the ſame proportion betwixt the diſtance of the plumb-line from the foot of the maſt, and the height of the maſt, that there is betwixt G T, one inch, the diſtance of the center of gravity, G, from Y Z, the vertical of the metacenter, and g G, the diſtance betwixt the metacenter and the center of gravity. If a plumb-line, of 50 feet long, is one inch diſtant from the foot of the maſt, we have this proportion, 1 : 50 :: 1 (inch, the diſtance of the center of gravity from the metacenter) : 50 inches, which makes G g, the diſtance of the center of gravity, below the metacenter 4 feet 2 inches.

We may remark, that, in order to determine this exactly, it is not neceſſary to know the preciſe point in which the metacenter lies; it may be ſuppoſed in the middle of the breadth-line O C on the upper deck.

The ſmaller the weight is that makes the ſhip heel, ſo much the greater muſt be its diſtance from the ſhip; however, an error of ſome inches, in the horizontal diſtance of the weight, will be ſcarce perceptible.

In fine, where neither the ſituation of the center of gravity, nor of the metacenter, is known, this experiment will at leaſt have one conſiderable advantage, that thereby we may know if theſe two points are always ſituated in the ſame proportion with reſpect to one another. We may, by this means, be in condition to reap the profit of all experiments made in former voyages, and eaſily find the ſhip's beſt ſailing trim, which the mariners call her ſeat in the water; and it is only by theſe repeated trials, that hitherto they have found it out. Though the builders always draw a water-line on their draught, to determine the preciſe draught of water the ſhip will draw when loaded; it is but too true, that they have no certain method to aſcertain this, and are altogether ignorant what ſhould be the difference of the draught of water afore and abaft.

All ſhips have a ſcale of feet and inches on their poſt and ſtem, to determine the draught of water afore and abaft: We may, by this ſcale, diſcover if the whole weight, and if the goods be ſtowed exactly in the ſame manner, with reſpect to the length of the ſhip, and likewiſe if the center of gravity be properly ſituated in reſpect of fore and aft. But tho' theſe be important diſcoveries, yet theſe alone are not ſufficient; for, admitting we have all theſe, the center of gravity may be either too high or too low; to aſcertain which, we muſt have recourſe to the preceding experiment. Thoſe who have the charge of navigating the ſhip,

and stowing the goods, make particular mention in their journals, of the weight of the cargo, the number of guns, the exact draught of water fore and aft; they need only make one remark more, which is, to specify the exact weight that will be necessary to be laid on the outside, in order to make her heel to a certain determined point.

When all this is given, it seems we know all the circumstances of the weight, which contributes to the safety and perfection of navigation; for what more can be desired, but the exact quantity of that weight, and the precise point in which it is united. It does not appear that the mathematicians who have examined this subject, have proceeded on any other supposition, than to render our examination compleat: These researches must be carried further. The weight of the ship may be exactly the same, and the center of gravity may likewise be situated in the same point, with respect to its height, and yet produce different effects. The effect will be exactly the same while the ship continues in the same situation; but it will be quite different, when the ship begins to rowl, and this may happen even in a calm, when a ship has no head way. If any exterior cause, as the continual motion of the sea, or a sudden shock of the waves puts the ship out of her horizontal situation, on recovering herself she contracts a motion which makes her incline to the opposite side, and her oscillations continue sometimes a considerable while; because the exterior cause is renewed, and acts a second time, which perpetuates the motion: This concludes the second section.

The third section contains three chapters.

The first on the point, round which the ship rowls, and how far the weight will conduce to her rowling.

The second. The figure of the ship being given, and the distribution of its parts, to know the direction of the oscillations.

The third chapter is to find the changes produced on the rowling, by the transposition of some parts in the ship, with some remarks on pitching.

As M. *Duhamel*'s remarks contain the substance of what our author has said on this subject, we refer our readers to our translation of his tenth chapter of his second edition, which is hereto annexed, and pass on to the conclusion of M. *Bouguer*'s second Book.

After expatiating on the great advantages that will accrue to navigating, by a proper situation of the center of gravity. He says, no labour should be thought too great to obtain it; and that the builders, endeavouring to make two ships equal in point of sailing, have made their bodies so exactly equal, and of the same figure, that no difference could be

<div align="right">perceived</div>

perceived in the very minuteft article : But thefe fhips were fcarce out of harbour, when their difference, in point of failing, fhewed itfelf in a very great degree, to the extreme amazement of all the beholders. This great difference cannot be attributed to the chimerical caufes, for they deferve no better name, to which they have recourfe.. Whence comes this difference, if not from the center of gravity, the fituation of which they had given themfelves no trouble to examine, if in the fame place in both? But granting that it may fo; yet when the cargo is differently ftowed, and fhe inclines more, or rowls to a greater or lefs degree; the immerged part ceafes to be the fame, and of confequence the fhip will, in this refpect be different, and produce different effects. It may here be afked, if the two fhips were to undergo M. *Bouguer*'s experiment, and the center of gravity, metacenter, &c. are found exactly the fame in both; and, if then, there fhould be any confiderable difference in point of failing, whence this could arife? For they are fuppofed to be rigged exactly both alike.

The chimerical caufes, he mentions, are, that fome imagine that a fhip's failing depends on driving wedges, in fome particular places; on fetting up the rigging, which may be too tight or too flack, on a piece of fail being fpread to the wind, or on a weight of 15 or 20 pound being fufpended in a certain place, &c. he fays there are not wanting feamen, who not knowing the caufes of fuch changes, have afcribed them to fome fuch caufes, and affured us they have confirmed them by experience : And what is ftill more ridiculous, it is ufual, on preffing occafions, to faw the gunwales, and to loofen fome parts, whereby they imagine the fhip's motion will be quicker, becaufe they are more fenfible of her motion themfelves. This is, fays our author, as if a poft chaife badly flung would go fafter, becaufe they who are in it feel themfelves more fuddenly toft and tumbled about. What ever may be in thefe remarks of our author, we may venture to affert, that a fhip, after being loofened, has got away from another that has gained on her very faft before.

M. *Bouguer*, in his third Book, examines the laws which fluids obferve in their fhock; as the wind in ftriking the fails, and the water in encountring the fore part of the fhip : He divides it into five fections.

The firft fection has eight chapters.

In the firft, he confiders how the impulfion of the wind on the fails, and the fhock of water on the bow, contribute to the failing, which he treats in a moft elegant manner, as a fpecimen of which we fhall give the following extracts.

F 2

When

When a ship sails out of the harbour, she acquires her motion by infinitely slow degrees; much after the same manner as heavy bodies, in their fall, arrive not at a certain velocity, but by an infinite repetition of the action of their weight.

The first impulsions of the wind greatly affect the velocity, because the resistance of the water might destroy them, for the velocity being at first small, the resistance of the water, which depends thereon, will be very weak; but the faster the ship goes, the less will be the force of the wind on the sails, whereas it is quite otherwise, with respect to the impulsion of the water, on the bow; because it augments in proportion to the velocity with which the ship sails. So the new degrees, which the effort of the sails adds to the motion of the ship are continually decreasing; whilst, on the contrary, those which diminish the resistance of the bow are continually increasing. The velocity is accelerated in proportion as the quantity added is greater than that subtracted; but when these two powers become equal, when the impulsion of the wind on the sails, has lost so much of its force, as not to act but in proportion to the force with which the resistance of the water acts on the bow, in the opposite sense; the ship then will go no faster, and will sail with a constant uniform motion. The great weight of the ship may be the cause of the ship's being so long in coming to her greatest velocity; but this weight makes nothing to the degree of velocity; and when the ship has once come to it, she afterwards goes on by her own intrinsick motion, and she can neither gain nor loose any new degree of velocity: She moves as by her own proper force *in vacuo*, without being afterwards subject, either to the effort of the wind on the sails, or the resistance of the water on the bow. If at any time the impulsion of the water on the bow should destroy any part of the velocity the impulsion of the wind on the sails will repair it, so the motion will continue the same; but it must be observed this will only be when these two powers act in a quite contrary direction to one another; otherwise, they will not mutually destroy one another. The whole theory of working ships, depends on this opposition and perfect equality; which should subsist betwixt the impulsion of the water, and the impulsion of the wind.

In the second chapter, he treats of the measure of the absolute shock of the water, and of the wind.

When, says our author, the water, or any other fluid, strikes a plane, every particle will act with greater or less force, according as the direction is nearer or farther from being perpendicular.

The

The effort of one particle is expreſſed by the ſine of the angle of incidence ; but at the ſame time that each particle makes a greater or ſmaller impreſſion, the number of theſe particles will be greater or ſmaller, according to their right, or oblique direction ; and this number is likewiſe expreſſed by the ſine of the angle of incidence, ſo the impulſion is in proportion to the ſquare of the ſine of the angle of incidence. When the angle is right, the impulſion will be the greateſt that it poſſibly can be ; whereas, when it is only 30 degrees, every particle will make only half the impreſſion, and there will be only half the number that will contribute to the ſhock, ſo the effort will be only one quarter.

But it is not only the obliquity of the direction in which the fluid gives the ſhock, that makes the difference ; it is likewiſe more or leſs, in proportion to the abſolute velocity, which it has, independent of the obliquity : As ſoon as the fluid moves faſter, the ſhock becomes greater, and is in proportion to the ſquare of the velocity. If the water, which for example, ſtrikes a ſurface, acquires three times the velocity, every ſingle particle will act with three times the force ; but as there will be three times the number that make their effort, the whole ſhock will be nine times greater. This is a property which is common to all fluids, which makes their efforts ſometimes very prodigious. Salt-water, for example, running at the rate of one foot in a ſecond, will have but a ſmall effect, but if the velocity is ten times greater, the ſhock will be a hundred times greater ; a force ſufficient to break thro' the thickeſt dykes.

Hence, when the ſame fluid ſtrikes the ſame ſurfaces with different velocities and different obliquities, the impulſions are as the product of the ſquares of their velocities by the ſquares of the ſines of the angles of incidence.

If not only the velocities, and the ſines of the angles of incidence be different, but likewiſe the ſurfaces ; the impulſion will then be in proportion to the extent of the ſurface, which will, nearly, be as the product of the ſquares of the velocities, and of the ſquares of the ſines of the angles of incidence, multiplied by the area of the plane, which receives the ſhock : I ſay, nearly, for it may happen that the ſhocks are not proportionate to the areas of the ſurfaces that receive them ; for inſtance, a ſurface of double the area may not receive exactly double the ſhock, on account of the greater or leſs difficulty with which the particles retire after having accompliſhed their ſhock.

Be that as it will ; if the preceding rules be admitted, we need only make ſome experiments on the ſhock of the fluids, by which we may judge of the force of the ſhock in all other caſes. It may be admitted as

a prin-

a principle eftablifhed by experiments, that the perpendicular fhock of falt water, whofe velocity is one foot in a fecond, upon a furface of a foot fquare, will be nearly equal to one pound feven ounces. If the velocity be greater, the impulfion increafes in the duplicate proportion : If the furfaces be greater, the effort is in proportion to their areas, and, laftly, if the fhock be oblique, the impulfion changes according to the fquare of the fine of the angle of incidence.

Upon the whole, if the velocity of water, or of any other fluid, be known, we need make no doubt about determining the force of the fhock ; but it is not fo with refpect to the wind. The denfities of the air are very variable, and are feldom fufficiently known ; fo it will be better to endeavour to determine the force of the wind immediately, without perplexing ourfelves to deduce it from the velocities. There have been feveral inftruments contrived by the ingenious for this purpofe ; to thofe who are not furnifhed with any, I recommend the following, which is very fimple, and I found it very ufeful in practice.

This Anemometer, is only a piece of light pafte-board applied to a fort of fteel yards, which performs its office by a fpring. The pafte board A B D E, *Fig.* 11, is 6 inches fquare, faftened to the rod C F, which is put into the pipe F G, and refts on a fort of fpring in the bottom of the pipe ; the piece of pafte-board being placed directly againft the fhock of the wind, the rod C F will prefs the fpring with greater or lefs force, in proportion to the impulfion of the wind. There is a rowler at F, in the mouth of the pipe, on which the rod C F moves, to take off the friction. The rod being graduated, we have the quantity of the impulfion of the wind, in pounds and ounces, in the fame manner that the fteel-yard gives the weight of any thing elfe ; but as the wind may be variable, the impulfion may move the rod backwards and forwards ; fo, to eftimate the quantity of the impulfion, we muft take a mean, betwixt the leaft and greateft. One of the principle advantages of this inftrument is, that we need only place the pafte-board parallel to the furface of the fails, without regarding the obliquity of the fhock, by this means it will be eafier to determine the quantitiy of the whole impulfion that makes the fhip fail, and, from that, be able to judge whether the mafts will be in danger. I prefume it will not be fafe to charge a foot fquare, with a weight of fix pounds. In *France*, the velocity of the wind is about 50 feet in a fecond, if it be in winter ; but if in fummer it will be about 60 or 63, and ftill more, over all the torrid zone. This is only its relative velocity, which it has with refpect to the fhip, whereas, its abfolute velocity is much greater, and is fufficient to overfet the fhip, and if on land

would

would overturn houſes, and tear trees by the root out of the ground. The reaſon of what our author advances here, I take to be, that the houſes or trees do not go from the wind; whereas, the maſt of the ſhip, before it breaks, forces the ſhip a head, and as it were, runs away from the ſtroke, which cannot be the caſe of any thing that is faſtened in the ground.

The Anemometer may likewiſe ſerve to meaſure the effort of the water, as well as that of the wind. In the builder's yards, where they have every thing that is needful for the purpoſe, they may eaſily make a ſmall bow of wood, ſimilar to the bow of the ſhip, and then, inſtead of the paſte-board A B D E, *Fig.* 11, fix this ſmall bow to the rod C F, which being expoſed to the ſhock of the water, we ſhall then have the quantity of the effort in pounds and ounces; we may ſee, by the direction of the rod, in what direction the bow receives the ſhock. Laſtly, we may re- peat the experiment, by expoſing to the ſhock of the fluid, a plane equal to the baſe of a conoid, which repreſents the ſmall bow; by which we ſhall perceive how much the ſhock of the fluid is leſs on the bow, than on the midſhip frame. Theſe mechanick experiments may help us to judge of the impulſions which ſurfaces receive in moſt caſes; but the gene- ral method is, to reduce the impulſions which curve ſurfaces receive, to thoſe which fall on plane ſurfaces, in order to which the curves muſt be divided into ſuch a number of ſmall parts, that they may be deemed ſtrait.

In the third chapter, the impulſion of fluids, on different figures, is conſidered; at firſt on a bow formed by two ſtrait lines.

Let the bow B A D, *Fig.* 12, be formed by the two ſtrait lines A B, and A D, and the direction of the ſhock be in an infinite number of lines parallel to the axis A C. The angle of incidence will be equal to the angle B A C, or to half the angle B A D, and, if we multiply each ſide A B and A D, by the ſquare of the ſine of the angle of incidence, we ſhall have the whole abſolute impulſion which exerts itſelf on each ſide, in the perpendicular direction of the line E F; let this be repreſented by the ſpace E F, and form the parallelogram E G F H. The ſides E G and F H, are parallel to the axis A C, and the other two ſides perpen- dicular to it. It is plain, that E G and F H repreſent that part of the impulſion which exerts itſelf in a direction parallel to the axis; and it is as plain that it will be leſs than the abſolute impulſion, in proportion as B C is leſs than A B. Since the triangles A B C and F E G, are ſimilar B C : A B : : E G : E F; ſo, inſtead of working for the abſolute impul- ſion on the ſides A B and A D, which partly deſtroy one another, we need

need only work for the direct relative impulfions, which act in the di-
rection of the axis, and mutually affift one another; but we muft not
multiply the fquare of the fine of the angle of incidence by the length of
each fide, A B and A D, for this would give us the abfolute impulfion;
we muft multiply the fquare only by C B, or C D. By this means, we
have the two direct relative impulfions; and then, if we multiply the
fquare of the fine of the angle of incidence, by the whole bafe B D, we
fhall have the relative direct impulfion on the whole bow.

If the angle at A, formed by the two fides, be 60 degrees, the angle
of incidence will be 30; and its fine, being half the fine of 90, the fquare
of this fine will be four times lefs; whence the direct impulfion which
the bow receives, will be but one quarter of that received by the bafe
B D, fince the angle of incidence is 45 degrees, and the fquare of it is
half the fquare of the fine of 90 degrees.

He then confiders the impulfion of the water on a bow, formed by a
femicircle, and likewife on a parabolick bow, which concludes the
chapter.

In the fourth chapter, he gives a general method of finding the im-
pulfion on curve lines, which he introduces with the following preface.

The impulfion of fluids on feveral other curve lines may be had by
an analyfis purely geometrical; but it will be neceffary to have recourfe
to algebra in thefe refearches, as it is only by this means we can extend
our views; for what is proved this way will be univerfal. We conceive
then, that, inftead of dwelling any longer on an examination which can
only be applied to particular cafes, we fhould afpire to make our difco-
veries general, which may be applied to all forts of curve lines that can
receive the fhock of fluids.

Of the Impulfion of Fluids in refpect of the Axis.

Let B A D, *Fig.* 13, be a curve line; A C its axis, A B and A D the
two branches perfectly equal; let x be the variable parts, A C or A H
of the axis, and let y be the correfponding ordinates B C and E H; let
dx exprefs the infinitely fmall parts H b of the axis, and dy exprefs
E F, the difference of the ordinates. Again, that I may not have occa-
fion to return here a fecond time, I fuppofe the fluid to move in the ob-
lique direction of the lines L e I, L e I, which make the angles F e I
with the axis of the curve, or with the line e F, which is parallel to the
axis. Let n reprefent the fine of 90 degrees, m the tangent of the angle
F e I; then $\sqrt{n^2 + m^2}$ will be the fecant of the fame angle.

The

The angle F *e* I is the oblique angle the ship's true course makes with the keel, or the lee-way; now, suppofing the curve B A D be the projection of the bow upon an horizontal plane, and A its extremity, the angle of incidence will be E *e* I, and will be greater on that side of the the curve where the fluid ftrikes it more directly, than on the other side, where it is more oblique. From the point I, let fall the perpendicular I K, on the fmall part E *e*, so fhall I K be the fine of the angle of incidence to the radius *e* I.

In order to find I K, the fine of the angle of incidence, our author has a very intricate algebraick inveftigation, by fluxions, and as it may be prefumed, many of our readers are not fo well verfed in algebra as to follow him in thefe deep refearches; I fhall endeavour to explain the whole by right angled triangles.

All that he propofes by this long procefs, is, to find I K, the fine of the angle incidence E *e* I.

The angle F *e* I, the lee-way, is given, which fuppofe 11° 15'; then the angle F I *e*, its complement, will be 78° 45'.

Let E F be 40 equal parts, and F *e* 50 equal parts; then E F : F *e* :: R : tan. angle I E K = F E K, now fubtracting the angle I E K from 90 degrees, we have the angle E I K, and this laft angle fubtracted from the angle F I *e*, there remains the angle K I *e*. The angles being thus found, our next bufinefs is to find the fides E *e*, K I, and *e* I.

In the right angled triangle I F *e*, R : fec ∠ F *e* I :: F *e* : *e* I; again, in the right angled triangle I K *e*, R : fine ∠ I *e* K :: *e* I : I K, the fine of the angle of incidence. Laftly, to find E *e*, the fmall portion of the bow which receives the fhock; in the triangle F E *e*, R : fec. ∠ F E *e* :: F *e* : E *e*. *See this operation by the logarithms.*

E F	40	1.602060
F *e*	50	1.698970
R		
Tan. 51° 20'		10.096890
Com. 38 40		

Angle F I *e*	78°	45'
Angle E I K	38	40
Angle K I *e*	40	05
Angle K *e* I	49	55

R————————
Sec. ∠ F *e* I 11° 15'   10.008426
F *e* 50   1.698970
I *e*   1.707396

Sine ∠ I *e* K 49° 55'   9.883723
I *e*   1.707396
I K   1.591119

R————————
Sec. ∠ F E *e* 51° 20'   10.204267
E F 40   1.602060
E *e*   1.806327

Supp.   G   Having

Having thus found I K, the fine of the angle of incidence, and E *e* the part which receives the fhock, multiply this laft, by the fquare of the angle of incidence, and the product will be the abfolute impulfion, as by the logarithms.

$$
\begin{array}{rl}
\text{I K} & 1.591119 \\
& \quad\quad 2 \\
\hline
& 3.182238 \\
\text{E } e & 1.806327 \\
\hline
& 4.988565
\end{array}
$$

The angle of incidence, on the other fide, will be 27° 25', the fine of which we may find by the fame proportions.

I fhall only remark on the whole, that our author fuppofes the angle of the lee-way to be known, on which the refult of the whole procefs depends; and as there is yet no expedient found to afcertain that angle, even to a quarter point of the compafs, it is to be feared we fhall gain very little by this general rule, therefore it is needlefs to detain our readers on this fubject, as the conclufions drawn from them are no ways to be depended on. Our author indeed attempts to determine the lee-way, which we fhall confider in its proper place.

The inference he gives, from the preceding procefs, is the refolution of this furprifing paradox, as he calls it, which is, that the relative direct impulfion depends neither on the nature of the curve which receives it, nor on the length of the axis A C, but only on its extreme breadth B D.

Let the curve B A D be an arch of a circle, parabola, or hyperbola; let it be a geometrick or mechanical curve, &c. fo the breadth continues ftill the fame; the impulfion it receives, in refpect of its axis, by a fluid which ftrikes it at an angle of 45 degrees, will always be the fame, and equal to half the fquare of the fine of 90 degrees, multiplied by D B the breadth; in other words, it will be half of that which D B would receive, fuppofing the fluid fhould ftrike it perpendicularly; fince that ftrait line may be confidered as the curve B A D, fuppofing the axis to be infinitely fmall.

Admitting all this, our author does not tell us how to apply this to the formation of the fhip's body, nor yet how his angle of 45 degrees is to be found.

In his fifth chapter, he confiders the impulfion of fluids on curve furfaces, particularly on a conick bow, and on a conoidale bow, formed by the revolution of an arch of a circle, which he inveftigates algebraically,

and

and from thence infers, that a bow, formed by half the revolution of a quarter of a circle, meets with double the refiftance in an horizontal that it does in the vertical, and concludes, that by confulting the trigonometrical tables, we fhall find the whole or abfolute refiftance, which is compofed of thefe two relative impulfions, exerts itfelf in a direction, which makes an angle of about 26° 34' with the horizon.

In his fixth chapter, he gives a method to find the impulfion on curve furfaces, by dividing them into a number of equal parts, which may be deemed plain furfaces, for which we refer to our Appendix, tranflated from M. *Duhamel's* extracts.

In his feventh chapter, he has fome remarks on the change of the impulfions on curve furfaces, when the fluid alters its direction, and obferves, that without perplexing ourfelves with examining all the oblique courfes a fhip may fail, it will be enough to calculate the refiftance, when fhe fails in the direction of the keel. It is certain, fays he, that the angle the fhip's courfe makes with the keel amounts to an angle of 45 degrees or 54° 44', to loofe the advantage of the figure, and ftill lefs, to change it to a difadvantage. I have, continues our author, in a memorial, communicated to the Academy of Sciences in 1733, proved this truth *a pofteriori*. When a plain furface, exactly circular, is expofed to the perpendicular fhock of a fluid, the nature of fuch a conoid that fhould cover it in fuch a manner, as thereby to meet with the leaft poffible refiftance, has been difcovered long ago; but this is limited to perfect conoids alone, and befides there is room to believe that it will not be the fame in a direct and oblique courfe. In order to clear this point, which has embarraffed the greateft mathematicians, I not only affumed any figure for the bafe, but even fuppofed the fluid to ftrike it obliquely, and was well recompenfed for my labour, for I thereby difcovered, that tho' the conoids of leaft refiftance be different for different bafes, yet it will be the fame thing in refpect to the impulfion, whether the courfe be direct, or oblique to the keel. Hence, fays he, we may be excufed from calculating the refiftance in oblique courfes, for it may be attained by calculating the refiftance in a direct courfe. We prefume, our author means, whatever be the form of that bow that will meet with leaft refiftance in a direct courfe, will likewife be the form of that which will meet with leaft refiftance in oblique courfes.

In the eight chapter, he purfues the fame fubject, and confiders the lateral impulfion, which he concludes with the following remark.

The bow that meets with leaft refiftance in a direct courfe, not only meets with leaft refiftance in oblique courfes, but is that likewife which is leaft

fubject

subject to drive to the leeward, which is a double advantage gained by forming the bow so as to give it that figure which will meet with least resistance in moving thro' any medium.

We have now given our readers a specimen of our author's method of examining the laws which the fluids observe in their shock; the wind in striking the sails; and the water in striking the fore part of the ship, which he comprises in the first section of his third Book. He proceeds, in the second section, by the same method, to attempt a general solution to all the problems relating to working a ship.

In the first chapter, he considers the velocity of the ship's sailing, in proportion to the velocity of the wind.

It has been always supposed, continues our author, that the velocity of the ship has no proportion to that of the wind. M. *d'Ons-en-Bray* was the first who thought this subject worthy of our attention, and it seems, has designed to reserve the resolution of this question to himself; the principles he was to proceed upon, can only be executed by experiments taken at sea; but I attempted a direct solution of the problem; and, continues M. *Bouguer*, as this is entirely my own, I shall give the following account of it:

Let a ship be 163 feet in length from the stem to the stern-post; the exreme breadth 44 feet 9 inches from out to out. I found the area of the vertical section perpendicular to the keel to be about 691 square feet. This section would receive the whole impulsion of the water, supposing there was no bow; but by reason of the convexity of the bow, the impulsion will be much less; the only difficulty will be to determine how much less it will be.

In examining a small ship at *Croisic*, I found the shock of the water on the bow to be one sixth and an half of that on the plane of the vertical section. The area of that plane carefully measured was 6687 square inches; the impulsion it received 66,870,000, whereas, by dividing the bow into 18 triangles, and adding up all the particular impulsions of each triangle, the whole sum was 10,245,735, nearly the $6\frac{1}{2}$ part of 66,870,000; for $10,245,735 \times 6\frac{1}{2} = 66,597,277.5$.

I imagine that in ships of war it will be less, and may be reduced to the ninth part; so that we may take 77 instead of 691 square feet for the area of the midship frame. But having occasion myself to visit our sea-ports, and to know the form of our great ships, I was forced to acknowledge that the shock on the bow was only one quarter, or at most one quarter and an half of that on the midship frame. This great difference betwixt the large ships, and the conoid of least resistance, is occasioned from this:

The

The conoid diminifhes gradually from the extreme breadth, at the midfhip frame, which is its bafe ; whereas, in fhips, the whole breadth is continued for a confiderable fpace, and then diminifhes fuddenly ; which will have the fame effect, as if the bow were fhorter, or had lefs rake. In fine, according to the prefent form of our fhips, if the area of the midfhip frame be 691 fquare feet, we may account about 150 fquare feet for that which receives the relative direct impulfion.

We muft now confider the effort of the wind upon the fails ; the area of the three fails on the main-maft, fhould be about 10316 fquare feet, and if the wind be on the quarter, moft of the fails on the fore-maft will bear a part of the impulfion, on which account we may add one half more, fo we have 15474 fquare feet for the area of the fails that receive the fhock of the wind ; which fhould be equal to the impulfion of the water on 150 fquare feet, as was before proved, to which the bow is fuppofed to be reduced ; befides the denfities of the two fluids fhould be confidered, for if one fluid be double or triple the denfity of another, or, which is the fame thing, if it be double or triple the fpecifick gravity, then the fhock will have double or triple the force. Mercury, for example, with the fame velocity will give an impulfion with fourteen times more force on an equal furface, than water ; becaufe Mercury is fourteen times heavier than water, and for the fame reafon water will make an impulfion 576 times ftronger than the wind, becaufe as M. *Mariotte* obferves, water is 576 times heavier than air, and their impulfions are as the fquares of their velocities. All this being admitted, let the velocity of the fhip be 100, then 150, the fquare feet that receives the impulfion of the water, muliplied by 576 the denfity of the water, and this product by 10,000, the fquare of the velocity, we have 864,000,000, which expreffes the impulfion of the water on the bow ; and this fhould be equal to the impulfion of the wind on the fails, that is to 15,474 fquare feet ; the area of the fails multiplied by 1, the denfity of the air, and this product multiplied by the fquare of the velocity of the wind, fo if we divide 864,000,000, which is the impulfion of the water by 15,474, the area of the fails, multiplied by 1, the denfity of the air, we fhall have 55,835, the fquare of the velocity of the wind ; the fquare root of which, is nearly 236. As this is only the velocity with which the fails are ftruck, we muft add to that, the whole velocity of the fhip, which makes the abfolute velocity of the wind 336 ; hence, the velocity of the wind is to that of the fhip's failing, as 336 is to 100. It muft be remarked, that if inftead of 576 we take 1100 for the fpecifick gravity of water to that of air, we fhall find the velocity of the fhip to that of the wind,

wind, as 100 is to 419; we fhall take a mean betwixt thefe two, be-caufe 576 and 1100, compared to unity, are near the limits of the pro-portion the denfity of the air bears to that of the water.

From the whole, we may conclude, that the beft failing fhip's go with two fevenths of the velocity of the wind; when the wind blowes two or three times ftronger, the. impulfion will be four or nine times ftronger, but the fhip will fail only two or three times fafter, becaufe the impul-fion of the water will be four or nine times ftronger. Notwithftanding all our author has faid on this fuhject, he tells us it cannot be ftrictly ap-plied to all forts of fhips, fo that the beft that can be faid of it is, that it may be an approximation, but feems to be of very little fervice in forming a fhip's body; I fhall therefore, only mention the heads of what he fays in the following chapters, with fome remarks as they occur.

Chapter II. Of the changes which the motion of the furfaces pro-duce on the fhock they receive.

The impulfion, fays he, will be confiderably lefs becaufe the motion of the furfaces makes the fluid, as it were, loofe a part of its velocity; he concludes this chapter with examining the fails of a wind-mill.

Chapter III. Of the changes which the motion of the fhip will pro-duce on the force and apparent direction of the wind.

Suppofe, fays he, the velocity 50 feet in one fecond, and the force on a foot fquare fix pounds; the area of the fails 15,474 fquare feet being ftruck perpendicularly, will receive an impulfion of 92,844; but, fuppo-fing the angle of incidence about 19 and a half degrees, the fine of which is one third of the radius, the impulfion will thereby be diminifhed to the ninth part; and if, by the motion of the fhip, the velocity of the wind be diminifhed to 25 feet in a fecond, that is, to half the abfolute veloci-ty, the impulfion will be four times lefs, and, confequently, the whole will be 36 times lefs, and reduced to $3863\frac{1}{2}$ pounds.

It is plain our author fuppofes the abfolute velocity of the wind, the angle the wind makes with the meridian, with the keel, and with the fails, to be given, and likewife the angle the fails make with the keel, and the an-gle of lee-way; hence the conclufions deduced from fuch uncertain *data* muft be more uncertain; our readers will, therefore, we hope, excufe us for omitting the application. We fhall only obferve, that in calculating the angle of lee-way, he condemns the common vanes, which, he fays, de-ceive us very much in determining the angle the wind makes with the fails, and recommends a quoit, fuch as children play with, as better a-dapted for that purpofe than any other inftrument hitherto invented. The principle from which he calculated the lee-way, is, fuppofing the angle

angle the fails make with the keel be 60 degrees, and the lee-way, at the fame time, four degrees, from thence he proportions the lee-way to all the angles the fails make with the keel to 30 from 90 degrees. The experience of all mariners is fufficient to confute his theory, and, it may be prefumed, the rules given in our *Englifh* navigation books, by allowing the lee-way in proportion to the fail a fhip carries, may be much more depended on, as they have been calculated from the journals of the experteft mariners ; for, after all his refearches, he refers to experience to find out this angle of four degrees, which he calls the lee-way ; and tells us, the mariners find it by fetting the fhip's wake in the water. This has been the fubject of his IVth chapter ; and in

Chap. V. he treats of the different velocities of the fhip, in different oblique courfes, and from his procefs infers, that, in order to double the velocity of the fhip's failing, fhe muft fpread fixteen times more canvafs.

The VIth and VIIth chapters contain the conftruction of tables to afcertain the velocity of the fhip's failing, which concludes the fecond fection.

In the third fection he confiders the fhip with refpect to her propriety of fteering well, either by means of the rudder, or of the fails.

The firft chapter is upon the fituation and number of mafts, and on the equilibrium, which fhould fubfift betwixt the head and after fails, out of which we fhall make the following extracts.

The principle, fays our author, having been already eftablifhed, touching the equality and perfect oppofition which fhould fubfift betwixt the impulfion of the wind, and the impulfion of the water, we may, from thence, deduce a fure method for placing the mafts. If the fhip has but one maft, it muft be, of neceffity, in the point C, *Fig.* 14, which is the interfection of the direction of the fhock of the water with the keel, in oblique courfes ; but if in place of one we put more mafts, they muft be before and abaft the point C, in Z and Y, fo that the fails on each fide that point be in equilibrium ; it is of great importance to determine this point C. According to the ordinary form of our fhips, the line of direction F C interfects the keel in about two ninths of the length from afore, or nearly five fixteenths of the whole length of the fhip ; that is, let B A, the length from the head of the ftem to the poft be 160 feet, C A will be about 50, this will not anfwer in all fhips. If the fhip be formed by two cones joined at the fame bafe, one for the fore and the other for the after part, the fore part five twelfths and the other part feven twelfths of the whole length, and the extreme breadth one quarter of the whole length, C A will then be about $48\frac{1}{7}$ of the whole length ;

length; but if the breadth D F be the fixth part of the length A B, then C A will be only the 46th part of the length.

It muft be remarked that thefe lengths agree only to the point C in its firft fituation, or firft oblique courfes.

Without being at the trouble to find this point by calculation, it may be done by a fimple experiment, on a model of two feet long, or on a fhip already built, by hauling it in the harbour with a tow line faftened to one fide of the bow; if this line be produced it will interfect the keel in the required point C. This point being once determined, we can place but one maft in that point, or if it be requifite to have more, they muft be placed on each fide in fuch a manner as to preferve an equilibrium betwixt the fails; for inftance, if we place the maft in Y, at lefs than the tenth part of the length from the center of effort C, without altering the other mafts, the fails muft be enlarged in the fame proportion the diftance from the point C is diminifhed

It may be demonftrated, that fhips that are built on purpofe for failing fhould be made confiderably longer, or which is the fame thing narrower, at the fame time the fails muft be narrower; and then we may have four inftead of three ftanding mafts; it is only by experience we fhall difcover if the thing be practicable; but they muft be fo placed that the total of the moment of the head fails be equal to the total of that of the after fails, on each fide of the point C: We may eafily difcover if the equilibrium betwixt them fubfifts.

The area of the main and main-top-fails of a fhip of the firft clafs is about 9500 fquare feet, and that of the fore and fore-top-fails, about 8040, nearly, in an inverfe proportion to their diftances from the point C, and multiplying each area by its diftance from the point C, we have their refpective moments. The diftance of the main-fail from C is $32\frac{1}{4}$ × 9500 makes 306,375 its moment, and the diftance of the fore-fail $38\frac{1}{2}$ × 8040 makes 309,540 the other moment.

We may without doubt narrow the fhips confiderably, if we be allowed to increafe the number of the mafts; if we have four mafts the fore-maft Z muft be as near as poffible to the point A, the extremity of the bow, and two main-mafts, one in P, if poffible before the point C, and the other in Q abaft it, and likewife abaft the middle of the fhip; the fails of thefe three will be in a perfect equilibrium, or which is the fame thing, the moment of the two firft will be equal to the moment of the third, obferving, at the fame time, to make the fpace P Q a little more than the fpace P Z, nearly in proportion, as the fum of the areas of the two main-fails is more than the fum of the areas

of

of the other main-sail and fore-sail. Lastly, the mizen-mast must always be in Y, or a little further aft. The use of the sail on this mast is to preserve the equilibrium, when the sea takes the ship on the after-post, so that the point C comes nearer the middle of the ship. The sails on the bowsprit have likewise their proper use and have a contrary effect to that of the mizen.

Our author then tells us, that if we push this to the utmost rigour, we may, instead of four, have a great many standing masts, and gives us a rule for placing them properly; but as it may be presumed this is an experiment that will scarce ever be tried, I shall omit it.

The second chapter is on the figure a ship should have in order to make her steer perfectly well with her sails, of which we here subjoin some extracts.

The only means, says our author, to attain this is to make it so that I C, *Fig.* 15, the direction of the shock of the water in the oblique courses, shall always pass thro' the center of gravity G: This has put the builders under a necessity of making the fore part full, tho' they alledge a quite contrary reason for doing it; which is, that thereby a ship will divide the fluid with a greater ease; and to prove this, they tell us that fishes are broader at the shoulders and head, than at the tail, and that a mast will tow best with the butt end foremost; these pretended reasons have gained such credit as to be adopted by several eminent mathematicians; but they do not consider that the author of nature created fishes, living creatures, with a head, stomach, &c. and it is not certain that their form is the properest for dividing a fluid, since perhaps they must loose some part of that advantage, in order to gain some other of which we are altogether ignorant. As to the mast, the only reason for towing it butt end foremost, I think, is, that the rope may not slip over the end; but, continues our author, we may reconcile the whole, by saying, that this form is proper, not to make the ship sail faster, for we are sure it will have a quite contrary effect, but to make her steer well. It happens unluckily, that we must loose a little of the first advantage to gain some of the other, and as we have not arrived at that perfection, to ballance them perfectly, because they are of different kinds, we must have recourse to experience, to discover the proper mean betwixt the two: Notwithanding, our author seems here to think that making a ship full before should not be, because the form would thereby resemble that of fishes; yet, in *Page* 59, he tells us the midship frame should be placed at five twelfths of the length from afore, and gives for one reason, that thereby the immerged part will better imitate the

Supp.   **H**   figure

figure of fifhes; and here, after all his laborious calculations, refers us to experience, which may poffibly give it contrary to his theory.

He afterwards propofes *Noah*'s ark, or the *Chinefe* junks, as beft formed for fteering, tho' not for failing; and, befides, they will be very fubject to drive to lee-ward; and the like may be faid of any other form which will make a fhip fteer well; and this he endeavours to prove by confidering a fhip formed by two cones; he chufes that figure not only to render his refearches more fimple, but becaufe, he fays, that figure differs little from the form of the folid of leaft refiftance. The inference he deduces from his algebraick procefs, feems to be only this, that thefe two properties of fteering well, and failing faft, are incompatible; and, therefore, we muft part with a little of the one, that we may not loofe the whole of the other. I fhall only remark, that the mariners have adapted a direct contrary maxim, that is, that a fhip that goes well, will undoubtedly fteer well, which has been confirmed to them by experience.

In the third chapter, he endeavours to determine the exact point where the extreme breadth fhould be placed, to render the fhip more fenfible of the power of the helm.

Many mechanicks, fays our author, have long ago difcovered, that when a power is applied to the extremity of a rod of equal weight throughout, in order to make it turn, the point of rotation will be about two thirds of the length; the rod being fuppofed of equal weight in all its parts; from whence our mariners infer, that the extreme breadth of the fhip fhould likewife be two thirds from afore, without confidering the cafe may be different. It has been the general practice to have it at that place, tho' they have by degrees drawn it nearer the middle, to render the bow fharper, and diminifh the refiftance; but it is certain, that, by fuch a change, they very much affift the action of the rudder, and herein is one of the particular circumftances, where we had better be entirely governed by experience, than by theory which continues imperfect, becaufe it has not been pufhed to a fufficient pitch; however, after a long algebraick procefs, he infers, that it fhould be placed neither at the middle, nor at two thirds, but nearly betwixt thefe two points, or about the twelfth part of the whole length before the middle.

In the fourth chapter is his method of knowing if the fhip, that is propofed to be built, fhall fteer eafily; or an examination of the motion which a body fhould take, when two powers exert their force, in contrary directions, to turn it on different fides.

The fifth chapter is only the fequel of the preceding, and, after examining the quantity and pofition of the fails, he concludes, that in that article, they had too much regard to the failing, to the prejudice of her

<div align="right">fteerage</div>

steerage; to remedy which, he says, we must either give the ship more head-sail, or if she is not yet framed, carry the midship frame farther forward. This ends his third section.

In the fourth section, he examines a ship with respect to the qualities best adapted to make her carry a good sail, in eight Chapters.

Chap. I. Of the mutual vertical effort formed by the united impulsions of the wind upon the sails, and the water on the bow.

Chap. II. Of the different stations of the ship, occasioned by the mutual vertical shock of the wind on the sails, and of the water on the bow; and the conditions requisite for properly masting a ship.

Chap. III. General principles to determine the greatest height the masts may have, so as not to be in danger of being dismasted, with some remarks on the power a ship of each class has to carry sail.

Chap. IV. The sequel of the preceding; to determine the limits of the highest mast, and the application of that rule to a ship of the first class, and the *Gazele* frigate.

Chap. V. After answering some objections, he examines what dimensions of the sails should be enlarged; and if proper to make the masts of a ship of different heights.

Chap. VI. To determine the most advantageous set of masts for a ship already built, the draught of water being assumed at pleasure.

Chap. VII. Of the form a ship should have in regard to her girt, best adapted to make her carry a good sail, and go fast thro' the water.

Chap. VIII. Of the girt of a ship, in respect of her length, most conducive to make her carry sail, with the means which may increase the velocity of her sailing to a very extraordinary degree.

Our author supposes the following particulars to be known, or at least attainable, by his preceding rules:

1st. The direction in which the shock of the water strikes the bow: This exerts itself in a double capacity, for it not only endeavours, by the resistance, as it were, to push her a stern, but likewise lifts up the bow; this angle, in his calculation, he supposes to be 48° 20', which the line D H, *Fig.* 16, makes with the horizon.

2d. The line S K, representing the direction of the wind on the sails, that is to say, the angle that line makes with the horizon; for tho' the wind always moves nearly parallel to the horizon, yet the impulsion on the sails is in a perpendicular to their surface, and if we consider the whole as united in I, the middle of the sail, the impulsion will be in a direction, perhaps not parallel to the horizon.

3d. The whole force of the shock of the wind on the sail, which, he says, may be had by an Anemometer.

H 2

4d. The

4th. The point N, which he calls the *velique*; to determine which we are to erect a perpendicular V T to the water line, to pass thro' the center of gravity Y; the interfection of this line, with the line D H, will give the point N, thro' which S K must pass; and when the center of the effort of the wind passes thro' this point, we may, without running any risk, give the fails what extent we please; it is presumed, our author means, this should be in the middle of the main-fail, but, he fays, if the maft be higher, it may be of dangerous consequence.

5th. The center of gravity of the immerged part, the center of gravity of the whole ship when loaded, and the metacenter; likewise their positions and respective distances from one another.

6th. The weight of the whole ship when loaded, and the exact draught of water. He fuppofes, in a firft rate, the center of gravity to be two feet below the metacenter, and the center of gravity, by the inclination of the ship, to be moved four inches from the vertical pasling thro' the metacenter, in which it was when the ship was upright; he likewife fuppofes the greateft inclination in a ship of the firft rate to be $9°\ 30'$. The inference deduced from thefe *data* is in page 564, that ships that are built on purpofe for failing cannot be too narrow, fo their length be preferved, and afferts, that to have a ship abfolutely perfect, she muft be infinitely narrow, on which account she muft have an infinite number of mafts and fails, and, in page 566, he affures us that a frigate, which is 18 or 19 times longer than she is broad, will fail fafter than the wind, and, if it were permitted to reduce her to half the breadth, if then the wind ftaikes the fails in a perpendicular direction, the fails at the fame time making an angle of $19°\ 30'$ with the keel, the ship will then fail with a velocity not only equal to the wind, but with a velocity a third or fourth part greater than that of the wind. I shall not take upon me to follow him in thefe deep refearches, but refer our readers to the original, as it is fcarce poffible, at leaft probable, that this should be ever reduced to practice, and fo have the theory confirmed by experiments.

In the fifth and laft fection, he confiders a ship, with refpect to the velocity of her failing, and the qualities neceffary to make her keep a good wind, and drive but little to lee-ward in oblique courfes. This takes up ten chapters.

Chap. I. An examination of the fimpleft figures which receive the leaft poffible refiftance from the mediums through which they move.

A table of the dimenfions of an angular and rectilineal bows, in an horizontal fenfe, which meets with leaft refiftance in paffing through the water.

Chap. II.

Chap. II. Of the conoid bow, which meets with the leaft poffible refiftance in dividing the fluid.

A table of the dimenfions of fuch a conoidal bow.

A table of the dimenfions of a new conoid, which will meet with leaft refiftance.

A table of the dimenfions of two conoidals, which meet with little refiftance, only when they are not wholly immerged.

Chap. III. A bafe being given, to find the figure of that folid which fhould cover it, fo that it fhould meet with the leaft poffible refiftance in paffing through the water.

Chap. IV. Of the formation of feveral other bows of leaft refiftance.

Chap. V. Of the bow of greateft velocity, or of that which will render a fhip more capable to carry fail, and at the fame time will divide the fluid with greater facility.

Chap. VI. To determine the figure of the bow of greateft velocity, when it is terminated by a fimple horizontal draught.

A table of the dimenfions of a curvi-lineal bow of the greateft velocity.

Chap. VII. Of the figure of the after part, when it is terminated by a fimple horizontal draught, and the method to be ufed in order to form frigates.

Chap. VIII. The fequel of the preceding; an examination of the after part, when it is a conoid, and how to form a frigate.

A table of the dimenfions of the conoidal after part, which contributes to the greateft poffible degree of velocity, by the impulfion it receives from the reflux of the water.

Chap. IX. Of the form of tranfports, and of fhips of war; and of a new form for frigates.

The firft folution. When the bow is formed by two vertical planes, which make an angle.

The fecond folution. When the bow is terminated by one inclined plane afore.

A particular method to form fhips of war and frigates.

Chap. X. The fequel of the preceding: An examination of the particular form propereft for the bow of a tranfport.

A table of the dimenfions of a bow of the greateft motion, which, our author tells us, differs from that of greateft velocity in fome cafes.

In this laft fection our author obferves, that it is very doubtful whether that figure which meets with the leaft refiftance in dividing the water, may be the moft advantageous to acquire the greateft degree of velocity; for it is poffible that a bow, which meets with a little more refiftance, may render the fhip capable of carrying a proportionate quantity of more fail;

fail; neverthelefs, the two bows, which we may diftinguifh, by naming the one that of the leaft refiftance, and the other that of the greateft velocity, fhould have fuch an affinity to one another, that one fhould, in a great meafure, partake of the moft effential properties of the other.

He then proceeds, in his ufual method, by an algebraic procefs, to inveftigate the form of feveral bows; and, to fave his readers the trouble of an intricate calculation, has conftructed tables of their feveral dimenfions, which we fhall hereto fubjoin and illuftrate, by forming one of the curves from thefe dimenfions, which may ferve as a fpecimen for all the reft.

TABLE I. *Of the Dimenfions of an angular and rectilineal Bow, in an horizontal Senfe, which meets with leaft Refiftance in paffing through the Water.*

Height or depth.	Half Br. or Ordinates.	Height or depth.	Half Br. or Ordinates.	Height or depth.	Half Br. or Ordinates.	Height or depth.	Half Br. or Ordinates.
0	899	374	1300	778	2000	1164	2900
14	900	408	1350	826	2100	1200	3000
79	950	440	1400	873	2200	1236	3100
132	1000	471	1450	918	2300	1271	3200
180	1050	502	1500	962	2400	1306	3300
223	1100	561	1600	1004	2500	1341	3400
265	1150	619	1700	1046	2600	1376	3500
303	1200	674	1800	1086	2700	1410	3600
340	1250	728	1900	1125	2800	1444	3700

TABLE II. *Of the Dimenfions of a conoidal Bow, which meets with the leaft paffible Refiftance in dividing the Fluids.*

Abfciffæ, or parts of the axis.	Half Br. or Ordinates.	Impulfions.	Abfciffæ, or parts of the axis.	Half Br. or Ordinates.	Impulfions.	Abfciffæ, or parts of the axis.	Half Br. or Ordinates.	Impulfions.
0	308	148993	4518	2545	1949062	41862	12040	14543335
6	317	155239	5194	2791	2189549	45383	12765	15615915
20	336	167905	5943	3053	2453469	49118	13520	16837987
44	364	186165	6769	3333	2743083	53080	14304	18132351
78	400	208184	7678	3631	3059421	57280	15119	19505003
125	444	236721	8675	3948	3404528	61727	15966	20949435
185	496	268916	9767	4284	3780198	66423	16845	22478039
260	557	307900	10959	6440	4188257	71386	17755	24089705
354	626	353607	12258	5016	4630586	76624	18699	25790519
468	704	405964	13668	5413	5109155	82139	19676	27580596
604	792	466875	15198	5832	5626246	87935	20688	29463846
766	890	536439	16852	6273	6182762	94086	21736	31444132
956	999	615734	18639	6737	6792289	100524	22817	33524478
1178	1118	705619	20565	7225	7426420	107285	23936	35708216
1434	1250	807369	22636	7736	8117090	114387	25090	38001324
1729	1394	922068	24861	8272	8867188	121835	26279	40399311
2065	1550	1050881	27246	8833	9648764	129642	27507	42913773
2448	1720	1194679	29800	9421	10493903	137820	28777	45545900
2880	1904	1355015	32531	10034	11395391	146380	30085	48298823
3366	2102	1533275	35447	10675	12355760	155334	31431	51462561
3911	2316	1730807	38555	11343	13377500	164694	32818	54183109

TABLE III. *Of the Dimenſions of a new Conoid, which will meet with leaſt Reſiſtance.*

Abſciſſæ or parts of the axis.	Half brea. or ordinates.	Abſciſſæ or parts of the axis.	Half brea. or ordinates.
0	100	5143	2593
23	122	8247	3451
55	150	10261	4632
97	183	14605	6269
155	226	20909	8559
233	280	30122	11788
340	349	43619	16379
675	552	64773	22961
962	701	93780	32478
1344	896	138926	46355
1876	1155	207366	66766
2619	1501	311931	97045
3665	1969		

TABLE IV. *Of the Dimenſions of two Conoidales, which meet with leaſt Reſiſtance only, when they are not wholly immerged.*

When the Axe of the Bow is elevated 1000 parts above the Surface of the Water.				When the axe of the Bow is elevated 2000 parts above the ſurface of the ſea.			
Abſciſſæ, or parts of the axis.	Ordinates, or half Breadths.	Abſciſſæ, or parts of the axis.	Ordinates, or half Breadths.	Abſciſſæ, or parts of the axis.	Ordinates, or half Breadths.	Abſciſſæ, or parts of the axis.	Ordinates, or half Breadths.
0	1045	1372	1800	0	2023	3223	3400
3	1050	1854	2000	5	2030	3825	3600
21	1070	2368	2200	14	2040	4449	3800
83	1125	2910	2400	36	2060	5093	4000
150	1175	3478	2600	89	2100	5756	4200
264	1250	4069	2800	248	2200	6438	4400
347	1300	4682	3000	433	2300	7136	4600
435	1350	5969	3400	636	2400	7851	4800
527	1400	7329	3800	1082	2600	8582	5000
721	1500	8753	4200	1570	2800	9327	5200
927	1600	10239	4600	2093	3000	10859	5600
1145	1700	11781	5000	2645	3200	12446	6000

TABLE V. *Of, the Dimenſions of a Curvelineal Bow of the greateſt Velocity.*

First Figure.				Second Figure.				Third Figure.				Fourth Figure.			
Abſciſ or parts of the axis.	Ordinates, or half Brea.	Impulſions.	Moments, or ſtability.	Abſciſ or parts of the axis.	Ordinates, or half Brea.	Impulſions.	Moments, or ſtability.	Abſciſ or parts of the axis.	Ordinates, or half Brea	Impulſions.	Moments, or ſtability.	Abſciſ or parts of the axis.	Ordinates, or half Brea.	Impulſions.	Moments, or ſtability.
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
126	203	146	0	356	169	31	0	200	65	7	0	125	31	2	0
399	531	333	9	712	335	61	4	400	129	13	0	250	62	4	0
627	714	406	46	871	402	71	10	703	225	23	1	500	122	7	0
758	788	425	83	1042	464	78	19	861	272	27	3	671	163	9	$\frac{1}{4}$
884	838	432	128	1136	493	81	26	1035	318	30	6	827	198	10	1
936	853	433	149	1200	510	82	31	1100	338	31	8	900	214	11	2
963	859	433	182	1272	526	84	38	1205	356	32	10	999	234	12	2
977	862	433	188	1310	533	84	42	1288	371	32	13	1174	266	14	4
987	863	433	193	1330	536	84	44	1333	379	33	14	1267	281	14	5
1001	865	433	199	1365	541	84	47	1401	387	33	17	1380	295	14	7
1014	866	433	204	1399	543	84	51	1466	391	33	19	1490	302	14	9

TABLE VI. *Of the Dimensions of the conoidal after part, which contributes to the greatest possible Degree of Velocity, by the Impulsion it receives from the Reflux of the Water.*

Abscissæ, or parts of the poop.	Ordinates, or half Breadths.	Abscissæ, or parts of the poop.	Ordinates, or half Breadths.	Abscissæ, or parts of the poop.	Ordinates, or half Breadths.	Abscissæ, or parts of the poop.	Ordinates, or half Breadths.
0	260	315	485	1538	996	4487	1831
2	262	382	521	1709	1054	4832	1914
9	271	456	559	1893	1114	5188	1998
21	283	539	600	2089	1177	5564	2084
37	299	630	642	2301	1242	5964	2174
59	317	729	686	2525	1309	6381	2265
86	339	838	732	2762	1378	6811	2358
119	364	957	781	3013	1449	7265	2454
159	390	1086	831	3278	1522	7738	2551
204	420	1225	884	3556	1596	8234	2652
256	451	1375	939	3849	1672	8750	2754
				4158	1750		

TABLE VII. *Of the Dimensions of the Bow of greatest Movement.*

Abscissæ, or length of the axis on the bow	Ordinates, or the depth of the Bow.	Impulsions.	Abscissæ, or length of the axis on the bow	Ordinates, or the depth of the bow.	Impulsions.
0	0	0	259	508	397
1	50	50	284	524	402
5	98	97	307	538	406
18	185	182	328	550	409
35	252	245	349	561	411
50	297	285	365	570	413
61	320	304	381	578	414
63	325	308	412	592	417
69	335	316	437	602	418
83	352	327	457	610	419
102	375	340	486	620	420
126	400	354	511	628	421
152	425	365	541	636	422
179	448	375	586	645	422
206	470	385	612	649	422
233	490	391	628	650	422

Our author remarks on Table I, that in joining two furfaces, A B R S, (*Fig.* 17) the bow may be formed nearly to what the figure reprefents, and will meet with the leaft poffible refiftance, in paffing thro' the water, in a direct courfe, or in any oblique courfes which do not exceed 45 degrees. This bow has that particular property, that it will meet with the leaft poffible refiftance, without regarding how deep it finks into the water. It is not the curves of the ridges, A I S, and B H R,

B H R, of which we give the abfciffa and ordinates ; it is of that which refults from the fection of the furface A B R S, cut vertically and perpendicularly to its length ; the point A being the origin of the abfciffæ extending along D C.

On Table II. He fays, we muft take the value of each abfciffa from a fcale of equal parts, and lay it off from A to X, or to C, on the ftrait line A C, *Fig.* 18, beginning always at the point A ; and then make the perpendiculars X V and C D equal to the correfponding ordinates in the table.

We fhall now give our readers the fubftance of his Conclufion.

After having, to the utmoft of my power, fays our author, executed every part of the engagement I undertook, it will be proper now to recapitulate the principal things I have explained, efpecially fuch as relate to the figure of the fhip ; and I fhall make no fcruple again to affirm, that, I believe, I have given infallible rules to the builders, to determine their choice of the different plans that may be prefented to them of the fame fhip, We have, in the fecond book, explained all that concerns a fhip while a-float or at reft : We may know if the whole weight be proportional to the folidity of the immerged part ; if fhe has ftability or force to carry fail ; or if fhe carries her guns high enough out of the water : And, in the third book, we have given proper rules to affure us fhe will fail well ; drive but little, when clofe hauled upon a wind, and readily anfwer all the motions of the helm. All the other qualities are fubmitted to the proof of a calculation, which cofts but little labour : Even fuch accidents as feem to depend on very irregular caufes are confidered ; fuch as the duration of the vibrations occafioned by rowling, and thofe of pitching ; we may judge of them by examining the diftribution of the weights, and in what manner every particular weight is fupported in every different circumftance.

Geometricians think no labour too hard, and do not fatisfy themfelves with what knowledge they have acquired, but are continually pufhing their refearches to the higheft pitch ; notwithftanding all this, we muft fometimes have recourfe to experiments on fhips already built, which may ferve as a term of comparifon. By thefe experiments we may, in an inftant, difcover things which could not be done any other way, without a great deal of labour ; and, in forming another fhip, it may fuffice to take notice of their different dimenfions, and the neceffary caufes that may occafion fome alterations.

We have endeavoured, out of an infinite number of forms, to pick out the beft ; and where the difpofition of different parts contribute to

Supp.   I   carry

carry a certain property to a higher degree, we have fearched the moft advantageous combination, to determine the *maximum*. We may, with certainty, make which property we pleafe predominate, and at the fame time know how far we may carry the others.

We have fhewn, that the extreme breadth fhould be five twelfths of the length, from the fore part, which is the pofition beft fuited to make the fhip anfwer the motions of the helm; but it muft be carried a little further forward, to make her fteer well by the affiftance of the fails, though, by this means, the bow will become fuller, to the prejudice of her failing, and of that property which fhould make a fhip lefs fubject of driving to the leeward. It will be impoffible to reconcile thefe four properties; and, that we may not lofe too much of any one of them, we muft refolve to lofe a part of the others; and the fureft way, in moft cafes, will be to embrace that which moft favours the action of the rudder.

We have, in the firft book, explained feveral methods of defcribing the midfhip frame, which may be improved by the remarks in the fecond and third books.

Suppofe we cannot perfuade ourfelves to abandon the common practical rules, nor venture at once to go to the utmoft point of perfection, yet it is to be wifhed, that the breadth and depth fhould bear but a very fmall proportion to the length; it is a matter of great importance, and merits the utmoft attention of the builders. The fection of the midfhip frame fhould be a triangle in light frigates, but a rectangle in fhips built for burthen. In thefe laft, the breadth is continued the fame as in midfhips, for a confiderable fpace, nearly the fifth part of the whole length. The common rules are very well adapted to the building of fuch fhips, and want very little amendment, but are very deficient in the frigates, which begin to narrow, both fore and aft, from the very midfhip frame. The fhips of war, as it were, keep a mean betwixt thefe two; they are fhips of burthen, but their great weight is fituated in a very inconvenient manner, their center of gravity being too near their metacenter; they muft, on that account, and on account of carrying their metal, be broader in proportion than other fhips.

The principal dimenfions being eftablifhed, we may form the ribbands, and fo the work will be compleated. We may ufe the method of approximation, delivered in the XIth chapter of the firft fection of the firft book; or conform to the tables, which we have with great pains calculated, and inferted at the end of the laft fection, that the practical part may receive all the benefit that may accrue to it from theory.

So far M. *Bouguer*; and here follows what M. *Dubamel* has faid on the center of gravity.

Abridg-

Abridgement of what M. DUHAMEL *has said in his second Edition on the Center of Gravity.*

M. DUHAMEL in this edition, has given us an additional Chapter, wherein he explains a method to find, whether or no a ſhip will carry ſail.

The principle on which he fixes the ſtability or ſtiffneſs of a ſhip is the proper fixing the center of gravity of the whole body, including, as well, the maſts, yards, guns, &c. that are above the water, as the ammunition, ballaſt, &c. that are below the water; and in order to give us a diſtinct idea of that term, the center of gravity, he proceeds in the following manner:

It is eaſy to conceive that the ſame quantity of any matter may be put in different forms, but it will ſtill be the ſame weight; for a piece of lead in form of a globe of one inch diameter, may be extended ſo as to cover a circle of one foot or more diameter; but it is plain the lead will be the ſame weight in both forms, and if it were poſſible to preſs it ſo as to become a globe of one eighth of an inch diameter or leſs, this ſmall globe would weigh as much as the other great one; but becauſe the parts of matter cannot penetrate into one another, this cannot be effected. Let us then ſuppoſe the whole weight of the globe A (*Fig.* 20.) to be united into one point *a*, and we ſhall have an idea of what in mechanicks is called the center of gravity.

The center of gravity then, of any body, is that point, whether it be within or without that body by which if it was ſuſpended, or upon which, if it were ſupported, it would reſt immoveable in any ſituation, as if the weight of the whole body were united in that ſingle point. Hence, to find the center of gravity of any body, is to find that point, upon which, if the body reſted, all the other parts would be in an equilibrium. It will be neceſſary, firſt, to ſay ſomething of the equilibrium; for then we ſhall eaſily explain what is to be ſaid on the center of gravity.

In treating of the equilibrium, I ſhall explain the balance, becauſe the uſe and conſtruction of the balance, and of the equilibrium, are founded on the ſame laws.

The balance (*Fig.* 21.) conſiſts of a beam A B, and a fulcrum or point of ſupport C, the center on which the beam moves, and if this be the

center

center on which the beam refts in equilibrio, it is the center of gravity of the beam; but as this point may be confidered as one of thofe that form a line, it may be confidered as the axis of the equilibrium; that is to fay, as if formed by a line pafling thro' the center of gravity: If we imagine a plane crofling the beam in the point C, we fhall then have an idea of the plane of the equilibrium; that is to fay, of a plane in which the center of gravity is to be found.

In order to make the beam of a balance true, the arms C A and C B, muft be exactly of the fame length, and likewife the weight of one arm muft be equal to that of the other, and the fulcrum muft be applied to the center of gravity.

Let us firft confider the line A B, abftracted from breadth and thicknefs, and, fuppofing all its points to be homogeneous, they will all have an equal tendency to the center of the earth; and if there be as many points betwixt C and A as there are betwixt C and B, the line will reft in equilibrio on the point C, which will point out the center of gravity for the point S on the arm A C; and the point S, on the arm B C, being equally diftant from the point C, and having an equal tendency towards the center of the earth, reciprocally deftroys the weight of each other; and there being, by fuppofition, the fame number of elementary points, betwixt A and C, as betwixt B and C, each will deftroy the force of its oppofite, and the line will reft in equilibrio, becaufe the line is fuppofed to have neither breadth nor thicknefs, the point C, will be in the center of gravity; but if the fulcrum be moved towards A, or towards B, it is plain the equilibrium will be broke, becaufe there being more elementary points on the one fide than on the other, there will be a preponderating force, which will caufe the line to incline; fo we may perceive that the center of gravity of a line, or of a rod, every where of equal thicknefs and breadth, and all its parts of equal weight, will be exactly in the middle of the line or rod.

It will not be amifs here to remark, that in finding the centers of gravity of lines, or furfaces, we need only confider their extent, becaufe as the matter of which they are formed is fuppofed homogeneous, all the parts will be equally affected with that tendency they have towards the earth's center, or that force which make bodies defcend, affects all the parts equally.

It is eafy to prove that the center of a parallelogram (*Fig.* 22.) is in N, the center of the figure; for, fuppofing the parallelogram to be formed by elementary lines parallel to A B, as we have already proved, that the center of gravity of a line is in the middle of it, if the line I K be

drawn

drawn thro' the centers of gravity, of the elementary lines parallel to A B, it will be the axis of the equilibrium in which the center of gravity, of the figure muft certainly be found. Let us then fuppofe other elementary lines parallel to B D; we fhall have L M another axis of the equilibrium, in which likewife the center of gravity muft be; and becaufe the point N is the only one, common to both axes, it muft be the center of gravity; hence, the center of gravity of a parallelogram muft be in the center of the figure; and for the fame reafon the centers of gravity of circles, ellipfes, of polygons, of any even number of fides, will be in the centers of the figure, as is evident by a bare infpection of the figures.

It will be as eafy to find the center of gravity of any triangle (*Fig.* 23.) for, fuppofing it formed by the elementary lines A B, we have C D, one axis of the equilibrium; again, fuppofing it formed by the elementary lines E F, we have G H, the other axis of the equilibrium, fo fhall N, the point of their interfection, be the center of gravity of the triangle; hence, the center of gravity of any triangle will be in the point of interfection of two lines bifecting any two fides, and drawn from the angles oppofite to thofe fides. If we fuppofe a regular pentagon, (*Fig.* 24.) formed by elementary lines A B, we fhall have the axis D C; again, fuppofing it formed by the elementary lines E F, we fhall have the other axis G H, fo fhall N, their point of interfection, be the center of gravity of the pentagon.

As by fuppofing all furfaces to be formed by lines, we have difcovered an eafy method to find the centers of gravity of regular furfaces, fo if we confider furfaces, as the elements of folids, we may as eafily find the centers of gravity of folids; for if we conceive the parallelopiped, (*Fig.* 25.) to be formed by an infinite number of parallelograms, parallel to *a b*, the centers of gravity of all the parallelograms will be in the center of the figures as was before proved; and if we draw a line *c d*, thro' all the centers of gravity, we fhall have the axis of the equilibrium, in which the center of gravity of the parallelopiped is to be found, and as all the parallelograms are equal, we may conclude that the center of gravity of the parallelopiped is in the middle of the axis *c d*; and, for the fame reafon, the centers of gravity of a cylinder, of a fphere, or of an ellipfoid, are exactly in the center of thefe folids.

As any prifm may be confidered as compofed of furfaces, or thin flices equal and fimilar to their bafes, and that a ftrait line drawn from the center of gravity of one bafe to that of its oppofite, paffes thro' all the

elementary

elementary flices, the center of gravity of all prifms, or cylinders, will be in the middle of that line which is the axis of the equilibrium.

As to the center of gravity of a triangular pyramid, it is plain it muft be in a ftrait line, drawn from the vertex to the center of gravity of the bafe ; for, let the pyramid be divided into elementary flices, parallel to the bafe, the centers of gravity of all thefe furfaces will be fimilarly placed, and, ufing the fame operation on all the fides of the pyramid, we fhall have different axes of the equilibrium ; their point of interfection, which will be one fourth of the length from the bafe, will be the center of gravity, and as a cone may be confidered as a prifm of an infinite number of fides, its center of gravity will likewife be in the one fourth of its axis from the bafe.

Hitherto we have confidered furfaces and folids as compofed of parts which are of equal weight ; but if the parts are of unequal weights, the folutions will be falfe ; for, fuppofing the part C B, (*Fig.* 26.) of the line A B to be gold, and the part C A to be iron, and the fpecifick gravity of C B 3, and that of C A 1 ; the fulcrum being in the middle of the line, the part C B will raife the part C A. In this cafe, in order to find the fulcrum, on which it will reft in equilibrium, we need only find the center of gravity of C B; which will be in *d*, the middle of that line, that part being fuppofed homogeneous, and, for the fame reafon, the center of gravity of C A, will be in *e*, the middle of the line C A. Let us now confider the whole weight of the line C B, united in *d*, and the whole weight of the line C A, united in the point *e*; all that remains to be done, is to find the center of gravity of two bodies (*Fig.* 27.) the weight of *d* being 3, and that of *e* 1 pound. In order to folve this problem, let the two bodies be joined by a rod that will not bend, and as the two bodies together weigh 4, divide the rod *d e* into four equal parts, fo fhall the center of gravity C, be in the third divifion from E, (*Fig.* 28) ; for the weight *d*, multiplied by the arm B C, will be equal to the weight *e*, multiplied by the arm A C. The arm of the lever A C, is to the arm B C as *d* to *e* ; we fhall explain this by an example taken from the common balance. Let A B (*Fig.* 29.) reprefent the beam of a good balance, four feet long, C the fulcrum ; now as A C and B C are exactly the fame length, that is, two feet each, and of equal weight; the beam will reft in equilibrium on the fulcrum C: If we fufpend to the extremities of the beam, the weights D and E of one pound each, the beam will ftill continue in equilibrium, becaufe the weight D of one pound is to the lever C B of two feet, as the weight E of 1 pound is to the arm C A of 2 feet : But fuppofe E 2 pound, and D 1, and placed as before,

it is

it is plain, the beam A B will incline to the side on which D is placed, because the weights are not reciprocally proportional to their distances from the fulcrum; and, in order to regain the equilibrium, we must shorten the arm of the beam C B, in the same proportion the weight E is augmented; so placing the weight E *(Fig. 30.)* at the point F, the two weights will then be in equilibrio; for now the weights will be reciprocally proportional to the lengths of the arms of the lever. Since D $=$ 1 lb $\times$ A C $=$ 2 feet; E 2 lb $\times$ C F $=$ 1 foot $=$ 2; which may be proved by experiment.

This may be demonstrated after another manner; for, supposing the weights suspended to the extremity of the beam, if they be equal, as in *Fig.* 31, the fulcrum must be at the point C, the middle of the beam; but if E be double the weight of D, then must the fulcrum be in the point F, two thirds of the beam from the end A; and then D : B F :: E : A F. Supposing then P, (*Fig.* 32.) to be 4 pounds, and R 12 pounds, and one suspended to each arm of the beam; in order to find the fulcrum, say, as 16, the sum of both the weights, is to 12, the greatest weight, so is M N, 8 feet, the length of the whole beam, to M F 6 feet, the distance of the fulcrum from M. Then P : F N :: R : F M.

Hence we discover a remarkable property in the lever; for in moving the fulcrum from C to F, (*Fig.* 31.) neither the absolute weight of the mass D, nor that of the arm of the lever A F, is augmented, since the beam is supposed to have no weight: And, to try this by an experiment, let there be as much weight added to B, as will occasion the beam to be in equilibrio on the point F, before we put on the weights E and D; nevertheless, the small weight will resist the action of the great one. So the relative force of D, in respect of E, is augmented in varying the velocity; for if we put the lever in motion on the fulcrum F, we shall perceive that in the time B describes an arch, suppose of 1 foot, A will describe an arch of 3 feet: Hence we may say, with *Des Cartes*, that it will take as much force to move ten pounds with 20 degrees of velocity, as to move twenty pounds weight with 10 degrees of velocity.

Let us endeavour to make this still plainer. If the two bodies, A and B, are of different weights, their center of gravity (or the fulcrum on which the rod E D, that joins them, will rest immoveable) will not be in the middle of the line; this will appear very plain, only by observing what will happen to the beam, when there is more weight in one scale than in the other.

In order then to find the fulcrum F, on which the beam shall rest in equilibrio, let us suppose it already found, and that E is double the weight

weight of D; it is evident, that E cannot have the leaſt motion, without giving D a motion at the ſame time; and the two bodies will continue in equilibrio till both are put in motion.

It is not then neceſſary, that the two bodies be of equal weight to pre-ſerve the equilibrium; but it will be neceſſary, that D have the ſame difficulty in moving that E has; and, becauſe E is ſuppoſed double the weight of D, it muſt take double the purchaſe to move it: Hence it follows, that the ſame force which will make E run over one degree, will, in the ſame ſpace of time, make D run over two degrees, provided E be double the weight of D; but if triple the weight, it will run over three degrees, and c as m, (Fig. 31.) for the effect is always propor-tioned to the cauſe. Hence this natural conſequence; if the motion of D be double or triple that of E, its relative weight will be double or triple its real; and if the motion of D be triple that of E, the equili-brium will be preſerved, although D be only one third of the weight of E. Now, if it be obſerved, that the fulcrum F, is three times the diſtance from A that it is from B, and that the arches of circles are in proportion to their radii; the arch, deſcribed by the point A, with the radius F A, will be thrice the arch deſcribed, by the point B, with the radius F B, in the ſame ſpace of time, juſt as the weight of E is triple that of D. Hence, to keep two bodies in equilibrio, their diſtances from their common center of gravity muſt be reciprocally proportional to their weights. D : E : : F B : F A.

We have made this digreſſion, to ſhew the difference betwixt the ab-ſolute and relative force of any body, which will aſſiſt us to underſtand the nature of *momenta*, which ſhall be treated of hereafter: We ſhall here ſhew how to find the centers of gravity of a ſyſtem of bodies of different weights, ſuppoſing them joined by an inflexible rod, paſſing through all the centers of gravity, the rod being conceived without any weight.

Let us then ſuppoſe the inflexible rod A B (*Fig.* 33.) paſſing through the centers of gravity of the ſeveral bodies *a*, *b*, *c*, *d*, *e*, *f*, whoſe abſo-lute weights are different; firſt find the center of gravity of two, as of *a* and *b*, which will be in *g*, if we make *g a* (the diſtance of *a* from the center of gravity) to *g b* (the diſtance of *b* from the center of gravity) as the weight of *b* is to that of *a*: Then conſidering *a b* as united in *g*, let us find the center of gravity of *g* and *c*, which ſuppoſe in *h*, and then conſider the weights *a*, *b*, and *c*, as united in *h*; and then uſing the ſame proceſs, on the other ſide, we ſhall find the center of gravity of *e* and *f* in the point *i*; and conſidering *e* and *f* as united in *i*, we may

find

find the center of gravity of e and d, which suppose in l. Now, the sum of the weights a, b, and c, being united in k, and the sum of the weights e and f united in l, we need only find the center of gravity of k and l, which will be the center of gravity of the whole system, composed of the bodies a, b, c, d, e, f; and if the center of gravity be at m, there must be the fulcrum, on which the whole system will rest in equilibrio; just as if a, b, and c, were put into one scale, suspended on the point k, and d, e, and f, put into another scale, suspended by the point l, they would be in equilibrio, provided m were the fulcrum on which the beam rests; because $k\,m$ is to $l\,m$, as d, e, f, placed in l, is to a, b, c, placed in k.

It is very plain, that if the bodies a, b, c, and d, e, f, (*Fig.* 34.) were placed in the same plane, on different sides of the axis of the equilibrium A B, they would remain in equilibrio upon that axis, provided their several weights be the same as in the preceding: The distance of each body from the axis A B, will be equal to the distance of each body from the center of gravity m (*Fig.* 33.), that is, A a, b M, c N, (*Fig.* 34.) equal to $a\,m$, $b\,m$, $c\,m$, (*Fig.* 35.) and P B, e P, and d O, equal to $f\,m$, $e\,m$, and $d\,m$.

It is likewise plain, that if in a system of bodies on the line A B, (*Fig.* 33.) their center of gravity m be in one of the bodies, it may be reckoned as a cypher, in regard to the center of gravity of the whole system; though its particular weight adds to the weight of the whole system.

Though my intention here is to confine myself to treat of the center of gravity, so far as is necessary to give my readers a clear understanding of the method of finding it in ships, yet I cannot allow myself to omit shewing how to find the center of gravity, of any number of bodies placed at random in the same plane; suppose a, b, c, d. (*Fig.* 35.)

The center of gravity of each particular body, (supposed to be known;) we must first find the center of gravity of a and b, joined by an inflexible rod, by the foregoing method, which suppose in e; and then considering a and b as united in e, find the center of gravity of e and d, suppose in f; lastly, considering a, b, and d, as united in f, we need only find the center of gravity of f and c, which suppose in g, so shall g be the center of gravity of the whole system. I shall conclude this subject, with some remarks on what has been said.

I. The center of gravity of any system of bodies, may be found without knowing the dimensions of their bulk, if their weights be known; for supposing a and b to be of different matter, (*Fig.* 36.) the one of

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ftone, and the other of wood, and each to weigh one pound, their center of gravity will be in *e*, the middle of the beam *a b*.

II. If the bodies be homogeneous, and of the fame fpecifick gravity, their centers of gravity may be found by their bulks, without knowing their weights; for, let the two bodies *a* and *b*, (*Fig.* 37.) be homogeneous, and let *b* be double the bulk of *a*, then will their center of gravity be in *e*, two thirds of the length of the beam *d e*; and this is found without having any regard to their weight, for *d c* being double *c e*; then *a : b :: c e : c d*.

III. As the center of gravity of any fyftem of bodies, confidered, abftracted from any weight, may be found by their bulks; it is in this fenfe, that the centers of gravity of lines, furfaces, or of any fpace whofe weight is not confidered, are faid to be found.

IV. We may likewife perceive that the center of gravity of any furface, limited by ftrait lines, may be found by reducing them to parallelograms, triangles, or any other regular figures, whofe centers of gravity may be found by the preceding rules; we may then fuppofe an inflexible rod paffing thro' thefe centers of gravity, and the center of gravity of the fyftem *a, b, c,* it may be found as in (*Fig.* 35).

It will be the fame with refpect of folids; for every folid may be divided into parallelopipeds, prifms, cones, or triangular pyramids, and by forming another fyftem by the centers of gravity of the feveral bodies, we may find the center of gravity of the whole fyftem by the rules already delivered.

We may now perceive how the center of gravity of a fhip may be found; for as the two fides A and B, (*Fig.* 38.) are equal and fimilar, it follows that the center of gravity muft be in a plane erected perpendicular to the keel, which will be in the plane of the equilibrium of the fhip, and tho' fhip's bodies are very irregular figures, they may be reduced, nearly, to regular ones, by dividing them into feveral fmall parts, and the center of gravity of each may be found as before; but as this method would be too tedious for practice. I fhall therefore attempt to fhew how it may be performed by M. *Bouguer*'s method of *momenta*.

The *momentum* of any heavy body, or of any extent confidered as a heavy body, is the product of that weight, or of that extent multiplied by the diftance of its center of gravity from a certain point affumed at pleafure, which is called the center of the *momentum,* or from a line which is called the axis of the *momentum.*

In order to comprehend this, it muft be remembered that we made a diftinction betwixt the relative and abfolute weight of any body; the relative

relative weight of any body confidered with refpect to that of any other body, or, with refpect to a point, is augmented or diminifhed in proportion to the diftance of that body, from the fulcrum, the abfolute weight remaining ftill unvariable ; or it is the relative weight which mathematians confider, when they ufe the *momenta*, by multiplying the weight, or extent of any body, by the diftance of its center of gravity from a point or line affumed at pleafure.

Example. Let B, (*Fig.* 39) be 6 pounds, A the center of the *momentum* of B ; and let A B be 4, then fhall 24 be the *momentum* of B, relative to A. Again, let B be 6 pounds, (*Fig.* 40.) A B 4, as before ; 24 will ftill be the *momentum* ; let C likewife be 6 pounds, and A C 3, fo its *momentum* will be 18, and the *momentum* of the two bodies will be 42.

If the two bodies in the fame plane are not in the fame direction, from the point A, that will make no alteration, if we confider them relatively to an axis A A 4, its *momentum* will be 24, and the diftance of C being 3, from the axis A A, and weight 6 pounds, its *momentum* will be 18, fo fhall the *momentum* of the two be 42 as before. I faid the center, or axis of the *momentum* may be placed at pleafure ; fo it may be placed betwixt two bodies ; if then it may be at the point A, (*Fig.* 42.) precifely bétwixt the two bodies B and C, fuppofe 6 pounds each, the *momenta*, of each being 12, they will be equal, and the center of the *momentum* will be in the center of gravity of the two bodies ; but if we place the center of the *momentum* in D, the *momentum* of C being $6 \times 3 = 18$, and that of B $6 \times 1 = 6$, the equilibrium will be deftroyed.

We may now begin to perceive the relation betwixt the center of gravity and the center of the *momenta*, but to make this ftill plainer, we fhall fhew that the fum of the *momenta* of all the bodies that compofe a fyftem is equal to the *momentum* of all the bodies confidered as united in their common center of gravity.

If we multiply all the weights 6, 5, 8, 4, 10, &c. which are placed along the beam A B, (*Fig.* 43.) by the diftance of the center of gravity of each, from the point A, which is affumed as the center of their *momenta* ; that is, $6 \times 1 + 5 \times 2 + 8 \times 3$, &c. and, laftly, 6×11 the the fum of all thefe products, will be 396 ; on the other hand, if we add the weights of all thefe bodies into one fum, that is, $6 + 5 + 8 + 4$, &c. $+ 6$, the whole will be 66 ; and this multiplied by 6, the diftance of the point C, the center of gravity of the fyftem from A, the center of their *momenta*, we fhall have 396 for the *momentum* of the fum of all the weights as united in C, the center of gravity of the whole fyftem, equal to the fum of all the *momenta* of the bodies taken feperately ; and

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that it will always be fo is evident, for, fince the point C is the center of gravity of the whole fyftem, in which all the weights are fuppofed to be united, and the point itfelf fo placed, in refpect of A, that all the weights placed betwixt C and B gain as much energy or force, by their diftance from the point A, as the weights, placed betwixt C and A, loofe of their particular relative force.

Hence, the *momentum* of the center of gravity, of a fyftem of heavy bodies, is equal to the fum of the *momenta* of the feveral particular bodies that form the fyftem; but it will be proper to remark, that if we confider the *momenta* of a fyftem, with refpect to a point A, which happens to be in the center of gravity of one of the extreme bodies, (*Fig.* 44.) it will make no alteration in the operation, only omitting that body which may be deemed a cypher; for, fuppofing the body A 6 pounds, then $5 \times 1 + 8 \times 2 + 4 \times 3 + 41 \times 5 + 9 \times 6 = 292$, and $6 + 5 + 8 + 4 + 41 + 9 = 73$, which, muliplied by 4, the diftance of the center of gravity of the fyftem from A, the product will be 292, equal to the former.

Let the bodies be the fame weight, and placed as before, and D, the center of the *momenta* (*Fig.* 45.), be betwixt two of the bodies, the fum of the weights, 8, 4, 41, 9, 6, 5, multiplied by their diftance from D, which is fuppofed the center of the *momenta*, will be equal to the fum of all the weights 6, 5, 8, 4, 41, 9, multiplied by the diftance of their center of gravity C, from D, the center of their *momenta*; obferving to fubtract the product of the weights of thofe on one fide of the point D, from thofe on the other fide, becaufe each endeavouring to turn the beam to its own fide, they will have contrary effects.

Suppofing D to be exactly in the middle betwixt 5 and 8; we have $8 \times 5 = 4 + 4 \times 1.5 = 6 + 41 \times 3.5 = 143.5 + 9 \times 4.5 = 40.5$, the fum of the whole is 194; and on the other fide $5 \times .5 = 2.5 + 6 \times 1.5 = 9$, their fum 11.5 fubtracted from 194 remains 182.5, exactly equal to the fum of all the weights $8 + 4 + 41 + 9 + 5 + 6 = 73$, which, multiplied by 2.5, the diftance of their center of gravity C, from D, the center of their *momenta*, is 182.5; but it muft be obferved, in this laft, we take the fum of all the weights, without fubracting thofe on the one fide from thofe on the other, becaufe they all tend towards the center of the earth; whereas, in finding the *momentum* of each particular body, they being fufpended on different fides, their effects will be in a reciprocal proportion to their diftances.

Laftly, fuppofe the center of the *momenta* be in E, (*Fig.* 46.) it is plain E equal 8 can have no *momentum*, becaufe its diftance from the

center

center is o; E × o = o, and then multiplying 4, 4 1, 9, by their refpec-
tive diftances from E, and, from the fum of their product, fubtracting
the product of the fum of 5 and 6, multiplied by their refpective diftan-
ces from E; fubtracting, I fay, this product from the fum of the other
products, the remainder will be equal to the fum of all the weights,
multiplied by the diftance of their common center of gravity C, from E,
the center of the *momenta.* Having thus proved that the fum of all the
particular *momenta* that compofe a fyftem are equal to the product of
the fum of all the weights, multiplied by the diftance of their center of
gravity, from the center of the *momenta,* it will thence follow, that, if
the fum of all the *momenta* be divided by the fum of all the weights, the
quotient will give the diftance of the center of gravity from the center
of the *momenta*; or, which is the fame thing, if the *momenta* of feveral
bodies, in refpect of a point or line, be divided by the weight of thefe
bodies, the quotient will be the diftance of their center of gravity from
that point or line which was affumed for the center of their *momenta.*

As for example, if it were required to find the diftance of C, the cen-
ter of gravity of the fyftem, (*Fig.* 47.) from A the center of the *momen-
ta*; the fum of the *momenta* is 292, this divided by 73, the fum of the
weights, the quotient 4 is the diftance from A to C.

As examples taken from things of common ufe are moft inftructive, I
fhall fhew that the conftruction of the fteel-yards is founded on the fame
principles; but let it be obferved, that we have no regard to the weight
of the beam A B, (*Fig.* 48.) or we fuppofe that the part A C, of the
beam is in equilibrium with the part B C, C being fuppofed the ful-
crum on which the beam refts; we likewife fuppofe the diftances A C,
C *e, e f, f g, h i, i k, k l, l m,* to be equal; and that the weight *e,* is one
pound.

Is is plain, if we put the weight *e* in E, we muft put one pound in
D, to gain the equilibrium; but if *e* be put in *f,* we muft put 2 pounds
in D, becaufe the *momentum* of *e* placed in *f,* is 2; and for the fame
reafon, if *e* be put in *g,* we muft put 3 pounds in D; if in *h,* 4 pounds;
if in *i,* 5 pounds; if in *k,* 6; if in *l,* 7 pounds; and, if in *m,* 8 pounds;
for *e* equal 1 pound multiplied by *m l,* equal 8, is equal to D 8 pounds
multiplied by A C equal 1.

Suppofing the points E, *f, g, h, i, k, l,* and *m,* had a weight of one
pound fufpended to each, thefe weights being all equal, and equally dif-
tant from one another; and fuppofing C, the center of their *momentum,*
we fhall have their fum by taking E once, *f* twice, &c. and *m* eight

times,

times, their fum will be 36, which, divided by 8, the quotient 4. 5, gives, the center of gravity of the fyftem C B.

Now we have got an eafy method of finding the center of gravity of a fyftem of heavy bodies. Thus, fince the centers of gravity of a fyftem of heavy bodies, or of furfaces, or of folids, will be in the fame place, and when we know the abfolute weight, or the extent of each of thefe bodies or furfaces, and the diftance of each center of gravity from a certain point, affumed for the center of the *momentum,* or from a line, which is fuppofed the axis of the equilibrium, we may always find the diftance of the center of gravity from that point which we have chofe for the center of the *momenta,* or from that line which we regard as their axis. It is from thefe principles that M. *Bouguer* has furnifhed the builders with an eafy method of finding the center of gravity of fhipping.

It now remains to apply thefe principles, which we have eftablifhed, to the finding of the center of gravity of a fhip, and to begin with the fimpleft operations, we only propofe at firft to find the center of gravity of the area of a fection of a fhip taken at the load water line, which is reprefented in (*Fig.* 49.) by A B.

I. The two fides of a fhip being equal and fimilar, the line A B may be confidered as the axis of the equilibrum, in which the center of gravity of that furface is to be found.

II. The curves that form the fides of that furface, being very irregular, muft be reduced as near as poffible to regular ones, by dividing the furface, with the ordinates *a a, b b, c c, d d,* obferving to place them at equal diftances from one another, and likewife the diftances muft be fo fmall, that the portion of the curves intercepted betwixt them may be confidered as ftrait lines, which will be near enough for practice, as we do not here propofe the utmoft degree of exactnefs.

III. Thefe ordinates will divide the furface A, into a number of parallelograms, fuch as *b d, d b,* which may be confidered as fuch, on account of their being fo very fmall, it is plain, the center of gravity of the parallelogram *b d, d b,* is at the point where the line *c c* interfects the line A B; and it will be fo with all the reft, fo the centers of gravity of all the parallelograms will form a fyftem diftributed on the line A B.

IV. To find the center of gravity of the fyftem, in refpect of A, which is affumed for the firft term of the *momenta;* we muft, as was before obferved, multiply the furface of each parallelogram by the diftance of its center of gravity from the point A, and fo, having the fum of all the *momenta,* we may divide that fum, by the fum of the furfaces of all the parallelograms, or by the whole furface A B, and the quotient will be the

the diſtance of the center of gravity from the point A, the axis of the *momenta*.

M. *Bouguer* has abbreviated this operation ; for, confidering that we muſt have the area of the whole ſurface A B, before we can obtain a ſolution, he finds that by the method delivered in Chap. VIII. of the Appendix, which is as follows :

1ſt. Divide the whole length in ſeveral equal parts *a a, b b, c c, d d, &c.*

2d. Meaſure all the ordinates *a a, b b, c c, d d, &c.* and add them altogether except the firſt and the laſt, of which we muſt only take one half of each.

3d. Multiply that ſum by the diſtance betwixt the ordinates, and the product will be the area of the ſection A B.

The ſecond thing to be had is the ſum of the *momenta* of all the elementary parts of the ſurface, which M. *Bouguer* has readily done, by multiplying each ordinate into its diſtance, from the point A ; then he takes the ſum of all theſe products, except the firſt and laſt, of which he takes only one half of each ; and by multiplying that ſum by the diſtance betwixt the ordinates, he has the ſum of all the *momenta* of the elementary parts of the ſurface, which he divides by the area of the ſurface, before found ; the quotient gives the diſtance of the center of gravity of the whole ſurface from the point A.

To explain this by an example, let it be required to find the center of gravity of a ſurface A B (*Fig.* 50.) 160 feet long, in order to which :

1ſt. Divide the ſurface by the ordinates *a b, c d, e f,* which are here 20 feet diſtant from one another.

2d. Omitting the line A, which here repreſents one of the tranſoms, becauſe we aſſume it for the axis of the *momenta.* It is 18 feet long.

Ordinates.	feet.	in.	lines.	Diſtant from A.	Product.
½A	18,	9			feet.
a b	23	0	0 ×	1	23
c d	28	0	0 ×	2	56
e f	30	0	0 ×	3	90
g h	31	0	0 ×	4	124
i k	30	0	0 ×	5	150
l m	28	0	0 ×	6	168
n o	21	0	0 ×	7	147
½ B	0	6	0 ×	8	4
Sum of all the Products					762
Diſtance betwixt the ordinates					20

f. in. lines.

Sum of the ordinates   200) 15240 (76 : 0 : 3¼

Suppoſe

Suppofe then we find the centers of gravity, of the furface of each fection contained betwixt the load water line and the keel; by the fame method, we fhall then have a fyftem of heavy bodies, which will have their centers of gravity in a plane erected perpendicular to the keel at their feveral diftances from the line A B, which is affumed for the axis of the *momenta*. In order then to find the pofition of the center of gravity of the hull, in refpect to the length, we muft find the pofition of the center of gravity of the fyftem, with refpect to the line A B, which we affume for the axis of the *momenta*, or for the firft term.. (*Fig.* 51.)

Having by the preceding operations found the area of each water-line, and its center of gravity, we need only multiply the area of each fection by the diftance of its center of gravity from the line A B, and add all the products, except that of the firft and laft, of which we muft only take one half of each, and then divide the fum of all the products, by the fum of all the areas, obferving to take only half the firft and laft, and the quotient will give the diftance of the center of gravity of the whole fyftem from the line A B, the axis of the *momenta*; we fhall explain this, by the following example:

	Areas of furfaces.		Centers of gravity from A B.	Products.
$\frac{1}{2}$ A	2000	x	76	76000
C	1800	x	82	147600
D	1000	x	90	90000
E	3700	x	80	56000
F	400	x	70	28000
$\frac{1}{2}$ Keel	55	x	80	4400
	4955			) 402000 (81 1 6

f. in. lines.

Having divided 402000, the fum of the *momenta*, by 4955, the fum of the furfaces, we have 81 feet 1.¼ inches, the diftance of the center of gravity of the fyftem from the vertical line A B, which will be nearly in the line H H.

It yet remains to find at what height above the keel in the line H H, the center of gravity of the hulk, or of the fubmerged part of the fhip, will be found: In order to which, let us take G *g*, the upper fide of the keel for the axis of the *momenta*, or the firft term; then it is only finding the *momentum* of each furface with refpect to the keel; (the diftances betwixt each fection being fuppofed 4 feet,) and then dividing the fum of all the products by 4955, the fum of all the furfaces.

Sur-

Surfaces.

ff	400	×	1	400
ee	700	×	2	1400
dd	1000	×	3	3000
cc	1800	×	4	7200
aa	2000	×	$2\frac{1}{2}$	5000

17000

Diftance betwixt   4

f.   in.   lines.

4955) 68000 (13   8   2   is the diftance

of the center of gravity of the hull above the keel, which will interfect the line H H in the point I.

In the preceding calculations we have fuppofed the hulk to be compofed of an homogeneous matter, all parts of which, in bulk, will be of equal weight; now, tho' this is a cafe that can never happen in a fhip, which contains various things of different weights, yet it may not be altogether ufelefs to the builders, fince all fhips of the fame rate having the different weights placed nearly fimilar to their lengths, they may find the center of gravity as above, and comparing it with the center of gravity of a fhip, which is known by experience to have all the good qualities that can be expected, we may difcover if the center of gravity of the fhip we are to build be properly placed, and befides it will affift us to underftand what follows.

It would be a very complicated and laborious tafk to find the center of gravity of a fhip properly mafted and rigged with all her provifions and furniture on board, and, tho' I do not defign to engage in the folution of that point, I think it would be unpardonable in me not to mention the action of a heavy body upon the fluid that fupports it, and the re-action of the fluid on the floating body.

It was obferved, in the beginning of this chapter, that the whole weight of any body may be confidered as united in its center of gravity, and that if it were fufpended by a line faftened to its center of gravity, that line would reft in a vertical pofition, and its direction would pafs thro' the center of gravity, and the center of the earth; but a body which floats in a fluid is not fupported by its center of gravity, but by the preffure of the environing filaments of water, which being confidered as infinitely fmall, each will act upon an infinitely fmall portion of the furface of the floating body, relative to the fpecifick gravity, and, in proportion to the height of thefe filaments, conform to a principle applicable to all fluids; namely, that the weight of a column of any fluid will be in propor

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tion to the specifick gravity of the fluid, and the height of the column multiplied by its base.

The pressure of the fluid acting upon all the submerged parts of the solid body, in the same manner that gravity acts upon all the parts of matter, the effect of such pressure will be united in a sphere of wax, of the same specifick gravity with the fluid, and which is intirely submerged, precisely to the same point as the center of gravity of the sphere of wax; we must then conceive that the pressure of the fluid acts immediately on the surface of the submerged body; but its action is united in its center of gravity, just as if it exerted itself upon every part of the solid body. Wax is nearly the same weight with water, and if one sinks a sphere or ball of that matter, its pressure on the fluid will be united precisely in its center, or in the same point in which the whole weight of the ball does act; so in that supposition the center of the pressure of the fluid coincides with the center of gravity, the action of each being united in the center of the sphere.

But this is not all; for as heavy bodies, by their gravity, endeavour to approach the center of the earth, in a vertical line passing thro' their center of gravity, tending directly towards the center of the earth; so the pressure of fluids endeavours to carry bodies in a vertical tending from the center of the earth towards their surface, and passing thro' the center of gravity of the submerged part which forces them towards the surface; so in any submerged body at rest, these two opposite forces coincide in the same vertical, acting in a quite contrary direction to one another.

We must conceive then all heavy bodies endeavouring to approach the center of the earth, by a secret force inherent to all the parts of matter; so, (*Fig.* 52.) the globe of lead *b* tends towards the center of the earth in a vertical stretching from the point of suspension *a*, thro' the center of gravity of *b*.

Those bodies that weigh less than a column of water, (of the same bulk), in which they swim, endeavour to rise by the pression of the fluid in a vertical line tending from the center of the earth to the center of gravity of the submerged body; so the globe of cork *d* tends towards the surface in a vertical line stretched from the point *c*, to which it is fastened to the center of gravity of the body *d*.

Let us then suppose two hooks *a* and *c* fastened to the opposite bases of the glass cylinder A, B, C, D, full of water, and let a ball of lead be suspended by a hair to the hook *a*, and one of cork, fastened by another hair to the hook *c*; it is plain, if the cylinder be upright, the ball of lead will descend towards *c*, with a force equal to its weight, lessened

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by the weight of the fluid it difplaces, and the ball of cork will rife with a force equal to the weight of water it difplaces, leffened by the weight of the cork, and if the hair that faftens them be cut, they will be affected by contrary forces, *b* defcending in the vertical *a c*, and *d* afcending in the vertical *c a*, they will meet in the fame point *e*, of the axis of the cylinder A B C D. But if we fuppofe the cylinder inclined as in (*Fig.* 53.) each body will take a different vertical, but parallel to one another; fo that if both were let loofe, *b* would defcend towards *f*, and *d* afcend towards *g*, and never meet. Let us fuppofe them joined by a rod *b*, *e*, *d*, of the fame weight with water; it is plain that each body will obey the force that acts upon it, *b* defcribing the arch *b g*, and *d* defcribing the arch *d b*, they will place themfelves in the fame vertical, parallel to *a f*, or *c g*; and if the force which the preffure of the water exerts on *d*, be greater than the force of gravity exerting on *b*; then will *d* draw *b* towards the furface of the water. On the contrary, if the force of gravity, acting upon *b*, be greater than the force of the preffure of the water, acting on *d*, then will *b* draw it towards the bottom: But if the forces be equal, *b* and *d* will reft in the middle of the fluid in the fame vertical.

The two bodies will then turn round a point in the rod *b*, *e*, *d*; but it will not be eafy to affign that particular place; it appears that if *b* endeavours to defcend with a greater force than *d* to afcend, in that cafe the center of rotation will be neareft to *d*, and, on the contrary, if the force that raifes *d* be greater than that which depreffes *b*, it will be neareft to *b*. Hence, in all heavy floating bodies which are at reft, the center where the effect of the gravity of the body is united, and the center where the effect of the preffion of the water is united, are in the fame vertical, tho' feldom in the fame point, as in a globe of wax which was fuppofed to be of the fame fpecifick gravity with water.

In order to apply thefe principles to fhipping, let us examine what would happen to a ftick, funk endways perpendicularly into the ftanding water. Now this ftick (*Fig.* 54.) being fuppofed all homogeneous, its center of gravity in air would be in *e*, the middle of the ftick; let us fuppofe the ftick fo light that it finks perpendicularly only to *d*, the one fourth of the length *a b*: Now the ftick being an homogeneous cylinder, the center, where the whole force of the column of water difplaced is united, will be in *e*, the middle of the fubmerged part.

Now, admitting all thefe fuppofitions, it is plain, when the ftick is in a vertical pofition, the two oppofite forces acting in the fame vertical line will deftroy each other, and the ftick will reft in that vertical pofition; but if the ftick be but a little inclined as in (*Fig.* 55.) the cafe will

be

be quite otherwife ; for the gravity which refides in the point *c*, exerting itfelf in the direction *c g*, it will concur with the preffure of the water acting in the direction of the line *e f* to overturn the ftick, or place it horizontally on the furface of the water.

The center of gravity of the ftick will always be in the middle of it, at the point *c*, becaufe it never changes its pofition with refpect to the ftick (*Fig.* 56.) and the center of the preffure of the water will always be in the middle of the fubmerged part, or rather of that fpace which is abandoned by the mafs of water difplaced, which will be in the point *e*, in the fame vertical with the center of gravity of the ftick, and fo the whole will be at reft.

Let us alter fome of thefe fuppofitions, and we fhall find the fame caufes produce different effects.

Suppofe then (*Fig* 57.) the part *a c*, of the ftick *a b*, to be, if you pleafe, three times the weight of *c b*, of the fame ftick ; the center of gravity of the ftick in air will then be towards *d*; the ftick being nearly of the fame weight with the column of water difplaced, will fink, fuppofe to *e*, the center of the impreffion of the water will be pretty near to *d*; but fuppofing it in *c*, or in any other point not below *d*, it is plain, when the ftick is inclined, as in *Fig*. 58, it will return to the vertical pofition ; for the force of gravity which acts in the direction of the line *d g*, will draw the end *a* towards *i*, and will concur with the force that refults from the preffion of the water in the direction of the line *c f*, to bring the ftick into its vertical pofition.

To make this ftill plainer, let us incline the ftick a little more ; we may eafily perceive, in *Fig*. 59, that if one purchafe be applied to *g*, acting in the direction of the line *g d*, and another purchafe applied to *f*, acting in the direction of the line *e f*, the extremity *b* would approach to *h*, and the extremity *a* to *i*, and the ftick would be in the vertical *h i*.

We may conclude, from this experiment, that any floating body will recover its vertical pofition, when the center of gravity is below the point where the force of the preffion of water is united. The ftability will be diminifhed, if the center of gravity be never fo little above the center of preffion ; and the body will overturn, when the center of gravity is raifed to a certain height above the center of preffure ; for, in this laft cafe, both act in concert to overturn the body ; whereas, in the firft, both join to preferve its upright pofition.

It was before obferved, that the point fhifts, on which the points *c* and *d* are turned round. We fhall now remark, Firft, That this will be according as the force of *c* or *d* predominates. Second, According to the

the pofition of c and d upon the ftick $a\,b$. Third, According to the difficulty that a will find in difplacing the fluid, to bring itfelf to i, or that b will find in bringing itfelf to h; and it is poffible, it may vary according to the different inclinations of the ftick. If this point of rotation were invariable, and a method of finding it could be obtained, we might then, without regarding the preffure of the water, know where to place the center of gravity, either to keep the ftick upright or horizontal. I fhall explain this by an experiment, which may be made by a well-known toy, or play-thing for children.

Every one has feen (*Fig.* 60.) the fmall ivory puppet, which keeps itfelf in a vertical pofition, upon the point of a needle, by the affiftance of two counter weights, c and d, which being joined together by a wire, are placed a good way below the pivot that fupports the figure.

The weight of the figure is efteemed as nothing, when compared with the weights c and d; fo the center of gravity of c and d will be towards m. If the figure is inclined towards i, the weight c will be carried towards e, and the weight d towards f; fo the center of gravity will fhift towards n; and as it ftrives to approach the center of the earth, and place itfelf in the vertical $m\,b$, the figure will recover its firft fituation. It is evident, that it will be quite otherwife, if the weights c and d are placed above the pivot, which fupports the figure; for if they are placed in i and k, and the figure be inclined never fo little, they will both act in concert to overturn the figure. We may likewife fee, that if they are placed in g and h, at the extremities of the plane of the pivot, which is fuppofed to be their center of gravity, they will not, in the leaft, contribute to keep the figure upright.

From this experiment we may infer, Firft, In order to keep the figure upright, the two weights, c and d, muft be exactly equal, or their difference adjufted by their diftance from the line $b\,m$, fo that their center of gravity may be in that line $b\,m$. Second, It will be neceffary, that the counter weights be below the axis of rotation of the whole fyftem. Third, The further the weights are below the axis $g\,h$, or the point b, the greater power will they have to recover the vertical pofition of the figure. Fourth, The nearer the weights are to the point b, or line $g\,h$, the lefs will be their power to recover the vertical pofition of the figure; and they have no power at all when the weights are placed in the line $g\,h$. Fifth, When they are placed above the pivot, they will both contribute to overturn the figure; and the greater their diftance above the figure, the greater their force to overturn the figure. In order then to

keep

keep the figure in an equilibrium, the center of gravity of the counter weights muſt be placed below the extremity of the pivot.

This important point, which M. *Bouguer* calls the metacenter, might eaſily be found in floating bodies, if the center of their motion were invariable and known.

It is not my intention to follow M. *Bouguer* through the various ſteps of his elegant inveſtigation of this point. We ſhall here obſerve, that there is a great difference betwixt M. *Bouguer*'s metacenter and the point of rotation of floating bodies. Though, in *Fig.* 60, they be exactly the ſame, yet in floating bodies it will be quite otherwiſe; and it is poſſible the point of rotation may be continually ſhifting, from the time the body begins its vibrations till it arrives at ſuch a ſtate as renders them regular; but it is not ſo with regard to the metacenter, as M. *Bouguer* has proved beyond diſpute; and *c* is certainly the metacenter, in *Fig.* 61, for the ſub-merged part is ſuppoſed perfectly round.

In order to apply what has been ſaid to ſhipping, let us examine the caſe of a cylinder (*Fig.* 62.) lying in the water, of which let *a b d* be a ſection perpendicular to the axis; let *e b f* repreſent the hold, which contains the ballaſt, &c. *e a* and *d f* repreſent the upper works; *e f* the line of flotation, and *b* the maſt, of the ſame ſpecies with the ſhip.

It was before proved, in Chap. VIII. of the Appendix, that the weight of the whole ſhip, including maſts and rigging, and all above water, as well as all below water, was equal to the weight of that column of water diſplaced by the ſub-merged part. Now, *g*, the center of gravity of the whole ſhip, and likewiſe *i*, the point where the preſſure of the water is united, muſt both be in the vertical plane *b b*; *s* muſt always be in the center of gravity of the ſub-merged part *e b f*, ſuppoſed homogeneous; or, which is the ſame thing, the center of gravity of the column of water diſplaced by the ſub-merged part.

It is evident that if, by bad ſtowage, the center of gravity of the ſhip be in *k*, and that of the preſſure of the water in *i*, the ſhip would incline ſo far to *e*, till the two centers, *k* and *i*, ſhould be in the ſame vertical *l m* (*Fig.* 63.) the ſhip would then come to her bearings, and lay faſt in the water, but in a very bad condition for ſailing.

Now, as the ſection of the cylinder *e l f*, when it is inclined, is ſimilar and equal to the ſection *e b f*, when upright, it will follow that *i*, the center of preſſure of the water, will be in the vertical *l m*; for it will always be in that line which biſects the line of flotation. In this caſe, the metacenter does not ſhift, becauſe the ſection being a circle, all the verticals will paſs through the center; tho', in any other form, this

point

point would shift higher or lower, according to the inclination of the body: But it may be found by M. *Bouguer*'s method, the inclination being given.

It will be proper here to remark, that the center of gravity of the ship will always continue in the same point, even when the ship heels; for if it should happen to be otherwise, by the shifting of the ballast, or any other accident, it would be of very dangerous consequence. If then the center of gravity be in g (*Fig.* 62.) in the line $b h$, it will continue in that line, when the ship lays over, as in *Fig.* 63; for it will not be in the vertical $l m$; but it will endeavour to place itself in that position; and the force of the pressure of the water, exerting itself in the direction of the line $l m$, both these efforts united will contribute to right the ship; and this will always be the case, if the center of gravity, g, be not placed above the point c towards b; for, in that case, the weight of the ship, and the pressure of the water, would both contribute to heel the ship.

We may, without having recourse to M. *Bouguer*'s geometric nicety, shew how dangerous it would be, to raise g, the center of gravity of the ship, to any considerable height above i, the point where the pressure of the column of water displaced is united, as in *Fig.* 64, if the center of gravity be placed in n, no sooner does the ship begin to heel; never so little, but the force of gravity acting in the direction of the line $n o$, will cause her to heel more, at the same time that the pressure of the fluid, united in the point i, acting in the direction of the line $i p$, will still raise the body higher; and both these forces will continue to act in concert, till they both come to be in the same vertical $b n$. It is now very plain, the more we raise the center of gravity towards b, the more we lower the center of pressure of the water towards b, the greater force will these two powers have to overset the ship: It is likewise plain, that if the center of gravity were placed in c, it would contribute nothing either to heel or right the ship. Lastly, the nearer we come to b, the more will it contribute to keep the ship upright; and when the center of gravity is below the center of pressure of the water, these two will act in concert to keep the ship upright.

The center of gravity must not, at any rate, be placed above the point c, which M. *Bouguer* calls the metacenter; but it will be proper here to remark, that C, the center of the arch $e b f$, (*Fig.* 61.) will serve to limit the center of gravity, even when the body is so light as to sink only to $g h h$, in an upright, or to $i l k$, in an inclined position; It is easy to perceive, that if the center of gravity be in the line $l m$, any

where

where betwixt c and m, the nearer it is placed to b, the greater power will it have to bring the ship upright, by struggling to bring itself into the line lb; on the contrary, if it be placed betwixt c and m, the nearer it is to m the greater power will it have to overset the ship.

The center of gravity, then must not be placed above the point c; but the ship may continue upright, tho' it be placed above n.

The misfortune is, that it is only segments of circles that have their metacenters in their centers, and could they be as easily found in ships it would be a great advantage: It is true, M. *Bouguer* has furnished us with a method to investigate the center of gravity, of a hull in form of a spheroid; but it is not my intention here to follow him in his researches, which he has carried on with all the clearness they are capable of.

As we confine ourselves to what is directly applicable to practice; it may suffice to have shewn what effect the weight of the ship, and the pressure of the water will have upon the stability of the ship; and that, by what we have collected from M. *Bouguer*, we may conclude that the metacenter should be placed a little above the line of flotation; but the center of gravity will be higher or lower according to the form of the bottom, or according to the manner of stowing the hold.

At first sight, it is certain that all the weight above the line of flotation helps to make the ship crank, and of consequence, the lighter the upper works the stiffer the ship, and it is by this method of lightening the upper works, that M. *de Goyon*, captain of one of his majesty's ships; made those ships carry sail which were before thought to be very crank.

The builders may vary the form of a ship, chiefly, in three dimensions, *to wit*, length, breadth, and depth: Let us examine how far enlarging of ships, in any of these particulars, will contribute towards making her carry sail.

If the length only, without altering the other dimensions, be enlarged, the center of gravity and the metacenter will continue the same height, so her stability in respect of inclination to one side will increase in proportion to the weight of the ship; and as the weight generally increases or diminishes in proportion to the length, we may say, that in ships that differ only in length, their stability will be in proportion to their length.

It will be quite otherwise, if we alter the breadth, for, by enlarging we gain, and by diminishing the breadth we loose a great deal of the stability; M. *Bouguer* has proved that the stability increases in proportion to the cubes of the breadths. For, supposing the bottom homogeneous. then, 1st. The increase of weight, and of consequence of stability, will be double the increase of the breadth. 2d. The additional weight will act

with

with fo much the greater force, as the length of the lever is increafed, or as the metacenter is raifed, and the height of that point is augmented in proportion to the fquare of the breadth ; hence, the ftability will be increafed in proportion to the cube of the breadth : For example, without altering the other dimenfions, let the breadths be doubled, we thereby double the weight, which, acting upon the arm of a lever, double the length will be quadruple, fo the fhip will acquire eight times the ftability. We may prove this by an experiment upon two models, the one double the breadth of the other ; if a ruler *b l* (*Fig.* 65) be erected perpendicular in the middle of each, and a plumb line faftened thereto, and if likewife an equal weight *n*, be fufpended to each lever *b m*, we fhall find, by the angle the plumb line makes with the ruler, the ftability will be as 8 to 1. We may likewife prove it, by comparing the different angles, made by the fame weight, or which, perhaps will be more fimple, let the inclinations be equal, and, fuppofe the one model three times the breadth of the other, then we fhall find that it will take 27 times more weight to produce the fame inclination, or the fame weight placed 27 times further from the axis than the other. Hence, in general, the ftability will be in proportion to the cubes of the breadths, provided all the other dimenfions be equal, fo if the breadth be as 1 to 3, the ftability will be as 1 to 27, for 27 is the cube of 3.

Experience has proved to the builders what theory has demonftrated to M. *Bouguer*, for without doubt it is for that reafon they place the extreme breadth of the midfhip frame pretty near the line of flotation. It would be very inconvenient to raife the breadth in midfhips ; but by raifing the breadth afore and abaft we gain in ftiffnefs. This will appear very plain, if we compare the fection that forms a rectangular parallelogram at the load water-line to one that forms a rhomboides, whofe acute angles are at the ftem and poft, which M. *Bouguer* has proved to be four times the ftability of the other. Now when, by increafing the breadth, the water lines become lefs fair, and therefore meets with more refiftance in dividing the fluid, it will not from thence follow that will hinder her failing ; on the contrary, as fhe will thereby carry a great deal more fail, it may affift her going.

We have hitherto confidered the bottom as homogeneous, but it is evident, the ftiffnefs of a fhip very much depends on ftowing the hold, as the center of gravity may thereby be lowered.

If we only increafe the depth, without enlarging either the length or breadth, all the ftability we can gain will be in the ftowage ; which is the next thing to be confidered.

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The feamen know very well that a fhip will not carry a ftout fail till loaded fo deep that the furface of the water may glance on the extreme breadth in midfhips, as the line *e f*, (*Fig.* 65.) or a little above *c d*, (*Fig.* 66.) and that they muft have a great deal of weight, fuch as ballaft, dinnage, &c. which ferves for no other ufe, but to bring the fhip to a proper trim in the water; for if fhe be too light, as in (*Fig.* 66.) fhe will lay over till her extreme breadth *g* refts upon the water; hence it follows, that a fhip that carries a good fail will heel but little, and ply well to the windward; but if, for want of ballaft, the fhip be not loaded quite fo deep, if fhe wants but a little, it will be no great difadvantage, for after fhe once comes to lay over to her breadth fhe will go no farther, and fhe will fail very well in that pofition.

There will be great danger in overloading a fhip, for then her guns will not be a proper height out of the water, an article of great importance, and fhe would meet with more refiftance in paffing thro' the water; for, admitting her to be loaded to the line *o i*, (*Fig.* 65.) fhe would difplace no more water by heeling to the fide *o*, and fo the preffion of the water would not contribute with the center of gravity to bring the fhip upright.

I fhall not prefume to determine this point to a nicety, fo as to admit of no exception. It may fuffice to fay in the general, that a fhip fhould be loaded to her extreme breadth; but it is not indifferent what manner of ballaft we ufe, for the quality and ftowage of the ballaft may very much increafe, or diminifh, the ftability. It is evident then we muft have no more ballaft than will load her to the extreme breadth; fuppofing 400 tons, together with provifions, &c. to be fufficient to load a fhip to her breadth, we muft put no more weight on board, but we may take heavier ballaft, by which means the center of gravity will be lowered proportionally to the fpecifick gravity of the ballaft. Hence is deduced the general practice of ftowing the heavy goods lowermoft, and the light uppermoft, whereby the fhip will be able to carry the greater fail.

It is not a matter of indifference how goods are ftowed in the hold; for, fuppofing a fhip loaded with lead, guns, iron, or and other weighty goods, her hold would not be near full, when loaded to her proper water line; and tho', by placing thefe goods on the floor, the fhip would certainly carry a great fail, yet fhe would fail very badly, and be in danger of being difmafted by her prodigious rowling and fudden jirks.

The mariners finding by experience how dangerous this would be have in a great meafure, found means to prevent it by the dinnage, whereby

the

the heavy goods may be raifed, this will make her rowl eafy, and go fmoothly thro' the water.

What we have faid of the ftability of fhipping has infenfibly led us to confider the rowling and pitching; we have already fhewn that the rowling may be very much prevented by ftowing the hold; the form of the bottom may likewife contribute thereto.

To explain this by an example; let us fuppofe the fection of a fhip, perpendicular to the keel, to be exactly round as (Fig. 63), it is plain, if this be agitated in the water, it will have nothing to fupport it, becaufe it difplaces no more water when inclined than when upright, and of confequence would rowl prodigioufly. But if we put a plank below b, fuppofe to g, to run quite fore and aft, it is plain, when the fhip is inclined to the right, the plank g will difplace a column of water to the left, which will retard her motions, and this obftruction will always act contrary to the way the fhip heels, and will very much diminifh the rowling, but will add very little to her ftiffnefs; for, admitting the fhip to heel as in (Fig. 63.) the plank b g would contribute very little to bring her upright. But the depth of the keel, the rifing of the floors, and the dead wood fore and aft, as in (Fig. 66.), will anfwer the fame purpofe as the plank b g.

In regard to the pitching, I am of opinion, the beft method that can be taken will be to proportion the capacity of every part to the weight it is to contain, and it will be very dangerous to depart from this rule; we have an inftance of it in the Juno of 60 guns, which, wanting capacity abaft, was always a very bad failer; and, notwithftanding all proper means were ufed to remedy this, by moving the iron ballaft forward, and the fore-maft guns aft, yet all their endeavours proved unfuccefsful, for fhe fometimes pitched to that degree, that her counter was under water.

It would not be advifeable to build a bad fhip on purpofe to try experiments; but when we find a fhip that has fome bad qualities, it will be of fingular ufe to find the proper means to remedy the fault.

In order to comprehend the means to be ufed to prevent the bad confequences of violent pitchings, let us fuppofe a fhip at reft, and a fea taking her afore; if the bow be well fupported; that is to fay, if the foremoft frame be pretty full, and her breadth line of the rifing of the floor not carried too high, this veffel will infallibly rife with the fea; it is true, when the fea leaves her fhe will fall again, but it will be eafily, becaufe the breadth increafes gradually, even above the load water line; and this fwelling of the body, being gradual, will hinder the fhip from falling with

sudden

sudden shocks; on the contrary, if she be very sharp forward, she will not pitch so much, but she will, in the sea term, bury herself under water forward, so that the foremost guns will be entirely unserviceable in a sea-gate.

We may perceive then, that their are two rocks to be avoided; though the breadth must be carried above the load-water line, to support the bow that she may rise to the sea, yet it must be divided in parts to prevent violent pitchings.

Let us still consider the ship pitching, or heaving and sending, in a sea-gate; if the foremost frames have no hollow, that is, if they be strait, from the breadth to the rabbit of the keel or stem, or if the vertical curve resembles a wedge, those ships will fall easy, because the breadth, increasing gradually, the resistance will likewise be gradual; but, on the contrary, if they are very sharp below, and the frames form a hollow from the rabbit almost quite as high as the breadth, it is plain she will meet with a very sudden shock, as the sea meets with no opposition, till, all of a sudden, it is resisted by the breadth; so that, in general, it is less dangerous to have a full bow, which will rise to the sea, than a very sharp one which will plunge the ship's fore-castle in.

Hence, the whole art consists in finding the proper mean betwixt these two extremes; that is, to give the ship such a form as may rise and fall easy into the sea, and likewise not hinder her sailing.

We have now given our readers the substance of what these two eminent mathematicians have said on the theory of Ship-building, and for further particulars, beg leave to refer them to the originals; they will then be able to judge how far they have succeeded in determining the necessary *data*; one thing may be remarked, that they at last refer us to experience, but experience seems not to agree with M. *Bouguer*'s principle, on which he says the velocity depends: For he asserts, that if the midship frame be carried before the middle of the ship, it will obstruct the velocity; because the bow will thereby become fuller; however he places it at one twelfth of the length before the middle, to give the helm more purchase.

I shall now give our readers an account of some experiments taken by one of our own countrymen, whose abilities are unexceptionable. He, by long experience, and unwearied application, has made several useful discoveries, which baffled the deepest researches of the most eminent mathematicians; his experiments prove beyond dispute, that we shall gain in point of velocity, in carrying the midship frame before the middle, perhaps

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at two thirds of the length from the after end. I shall not take upon me to assign the reason of this, but there is no disputing against matters of fact, perhaps it may be owing to what I said on that head, when treating of towing a mast, butt end foremost, or it may. be on account of the center of gravity, which will thereby be further forward; it must be allowed this last circumstance will give the helm more purchase, tho' it cannot be discovered by his experiments, the whole design of these experiments being to determine the form of that body which will go thro' the water with the greatest velocity, and to ascertain the most advantageous situation of the midship frame, and that this must be nearer the fore part than the after part, he has demonstrated in such a clear, elegant, and familiar manner, that I should only discover my own weakness, in presuming to say any more on that head; so I shall give it in his own words.

Of the Friction, or lateral Pressure of Water.

THE cylinders made use of in the following experiments were solid of seasoned oak, 36 inches long, by four inches and a half diameter; the sides were strait, and turned exactly round.

A, in *Fig.* 74. is the standard to make the comparison from; when the pieces 1, 2, 3, 4, 5, are screwed together, they make the cylinder B equal to A, these are drawn thro' the water with the end 5 foremost; until (by encreasing or lessening the weight a little at the roller or pully) the velocities agree.

After which take out 2, and put together 1, 3, 4, and 5, which makes the figure C to be one fourth part shorter than A, at which time it gains the velocity of one eighth.

Then take out 3, and put 1, 4, 5, together, and it makes the cylinder D; which being drawn against A, as before, it makes the velocity one fourth part more.

After which, if we join 1, 2, 3, 4, and 6, together, it makes the cylinder E, with no more difference from A, only that there is a direct flat superficies in lieu of a convex; this drawn against A, loses in velocity one sixth part.

Take off 6 and join 7; it makes the figure F, a concave, and, when drawn as before, it loses one fourth part of the velocity.

When the flat superficies is drawn hindermost, it loses one twenty-fourth part. When the concave is drawn hindermost, it loses the same one twenty-fourth part.

From

From such experiments, we may gain a proportion for lateral preſſure, or friction; we alſo ſee the great difference between a convex and a flat ſuperficies to ſeperate the water; and the difference between a concave end to ſeperate the water and a flat ſuperficies; alſo between a concave and a convex end; and alſo, that there is a ſenſible difference as to its ſeperating the water, by being foremoſt, tho' not ſo by the cloſing in of the water by being hindermoſt.

Theſe things may be of ſerviⅽe in theory, and ſeem capable of being improved by further experiments.

NOTES *relating to* EXPERIMENTS.

Method for knowing the lines of leaſt reſiſtance. Intended for the pur-poſe of forming the bodies of ſhips; alſo, relating to an attempt for finding the proportion for the friction or lateral preſſure of water.

Provide a ciſtern for the water as repreſented in the plate (*Fig. 75*), not leſs than 30 feet long, and divide it in halves by a partition length ways, that the motion of the water in one part· may not diſturb that in the other; obſerve, as the leaſt blowing of the wind diſturbs the ſurface, it is beſt to be under cover, namely, in a ſhed or warehouſe.

Obſerve the pullies, repreſented on the plate, be made very exact, the lines may be ſilk or *Indian* graſs.

There muſt be alſo a line ſtrained very tight over the middle of each water, and wires fixed upright in the end of each block or ſolid; which by the ends, turning back over the line, keeps the block or ſolid direct in its courſe.

At each end of the block is fitted a ſmall ſtaple, by which the lines faſten with a hook to draw the block; there muſt be time given between each drawing for the water to become ſtill.

The blocks muſt be as near as poſſible equal in weight, and ſwim truly level with the ſurface of the water; if they do not, it muſt be remedied by cutting out a ſmall piece, or by making a groove in the ſolid, and ſo trim the block by putting in ſmall ſhot.: The whole will require much care and exactneſs.

The figures repreſent ſolids, whoſe lengths are 2 feet 3 inches, and diameters ſomething leſs than one third of their lengths; theſe are made perfectly round, one end of theſe ſolids is of one ſhape, the other ends vary as the figures repreſent.

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The quantities and weights are made equal and drawn thro' the water, with equal power, that is, firſt make the ſtandard ſolids agree in velocity, then fix equal weights to the lines that paſs over the rollers.

Whoever repeats theſe, or proceeds in making other experiments will do well to obſerve, what weight nearly he chooſes to uſe; for, if the power is very ſmall, a little obſtacle may impede the motion of the ſolids too much. If the weight is great, the velocity will be too much for the obſerver to decide with exactneſs the difference of velocity between the two moving ſolids.

P O S I T I O N.

Theſe blocks being perfectly round, and as the water preſſes on bodies in all directions, therefore, theſe blocks are truly repreſented by ſingle lines in the figure A, B, C, D, in (*Fig.* 76.) and without having other lines of different curves intermixt with them; ſo that which ſoever of theſe ſolids ſhall have the greateſt velocity, has ſo far the lines of leaſt reſiſtance.

E X P E R I M E N T.

There were two blocks or ſolids repreſented by figure A, of equal weight, ſize, and velocity. This velocity was made equal by altering a little the weight that paſſes over the braſs roller; one of theſe ſolids is made a ſtandard to try the other, otherwiſe we could not have known ſo perfectly which end foremoſt, of A, would have the greateſt velocity.

Reverſe the ends.

A drawn againſt A equal velocity.
B againſt A gains in velocity about one 16th.
C againſt A loſes in velocity about one 70th.
D againſt A gains in velocity about one 9th.

H againſt A loſes about one 27th.
G againſt A loſes about one 16th.
F againſt A gains about one 14th.
E againſt A loſes about one 9th.

Obſerve, that if the braſs rollers are not exact, they will affect the motion of the ſolids; ſo that it is proper to change each ſolid, together with its weight, over each roller, for the ſame reaſon we change the weights to try ſcales. The roller which upon careful trial appears to increaſe the effect of the weight may be leſſened in the circumference, or the other increaſed in the circumference.

D hath the greateſt velocity, I ſay it is becauſe the breadth declines nearer the head than in the others, which eaſes the lateral preſſure ſooner than in the others. The extreme breadth of the

figure

figure B, is nearer the end, which breaks open the water fooner, but then the breadth is continued further aft, by a ftrait fide, fo that the friction is not eafed by the declining of the fides fo foon as in D, and therefore the difference in velocity is accounted for as before.

Experiment with the Solids I, K, L. (Fig. 77.)

I, and K, are two diftinct blocks, the extreme breadth of each is in the middle; they are equal in quantity, equal in length, and equal in weight, but not equal in breadth. The block K is narrower in the middle and fuller towards the ends: The block I is broader at the middle, and narrower towards the ends; they are drawn, and found that K hath more velocity than I, by one forty-fixth part.

L is the fame length, fame breadth, fame quantity as I; the extreme breadth of this is removed from the middle to one third of the length from one end, by which means one end is fuller, and the other juft fo much the fharper, and the floor fhorter; this drawn, the full end foremoft, againft I, gains in velocity one ninth part, and when the fharp end is foremoft, it lofes one ninth part.

Doth not this fhew, that if a fhip was built with the lines that form the body fimilar to the folid whofe breadth is in the middle, and if another was built with the lines that form the body fimilar to the folid whofe breadth is one third from the ftern, the latter would lofe of the former one ninth part of the velocity?

If another fhip was built, whofe lines that form the body were fimilar to the folid whofe breadth lay at one third from the head, it would outfail the fhip whofe breadth lay in the middle one ninth part. Alfo, that the fhip whofe breadth lay at one third from the head, would outfail the fhip whofe breadth lay at two thirds diftance from the head, two ninth parts of the diftance run.

The abfolute and relative force of a current of water, againft the forepart of a fhip, may be computed from the fines of the angles of incidence taken in many parts, as is defcribed by M. Dubamel, or fome other way equal thereto, as far aft as the midfhip frame; and as the midfhip, or the wideft frame may be placed in the middle, or further aft or further forward, and the quantity of the bulk remain the fame in the whole; fo by moving the midfhip frame further aft, the lines that form the fore end of the fhip thereby runs nearer a parallel to the keel, and confequently have the lefs abfolute refiftance to the current of water; but this accounts but for one part only, that is the refiftance of the cur-
rent

rent from the stem to the middle of the ship. Yet there is a friction, if I may so call it, from the lateral pressure of the water against the sides and bottom of the ship that must be considered also, which I will endeavour to explain in the manner following. Water, according to its depth, is by its own weight compressed together, against the ends, sides, and bottom, in all directions; if the body placed therein be not specifically heavier, the water will bear it up, and, in proportion, as the body is lighter, the more it will float out of the water; this is familiarly known, but the applying this to the present purpose may bear stating in this manner.

Water, or any liquid, placed in a box, or vessel of any figure, presses against all the sides with a force equal to its depth, and, at the same time, the whole weight on the bottom. On the contrary, when a vessel is placed in water, the water presses the sides and ends inwards, and upwards, under the bottom, with a force to bear up the vessel, ship, or any other figure whatever, that is not specifically heavier than the water.

The moving this body, as it is thus circumstanced, with the water pressing against it on all directions, must put all the parts of the water that are next, or near it, in a ruffle and sort of confusion; the particles at the fore-end of the ship, near the bottom plank, appear to be constantly removed by fresh particles of the current pressing in, and impelling against them, and so one after another; but when we come to a more strait part of the ship's sides, and the declining part of the ship's bottom, the particles next the plank are not so soon difpaced; this appears, from observing the grafs that grows on the sides of the ship; it shall be seen to grow right out, and wave backwards and forwards, from the sides of the ship, as if the water had no motion, when at the same time, the ship may be sailing three four or five knots an hour, or more : This is, in part the cafe when the ship's bottom is clean, but much more so when the bottom is foul. This atmosphere, or carrying part of the water along with the ship, is what I have here called friction, and is to be considered, and must be taken into the account of the resistance. In order to form some conception thereof, the solids, represented by the figures, were contrived, being turned exactly round, and the water pressing in all directions, they are by me esteemed as single lines.

By these experiments, it appears, that by moving the middle frame from the middle, nearer one end; that end unto which the widest frame is nearest, gives the greatest velocity, when turned foremost, and so contrariwife it is reverfe.

Supp.   N   Now

Now it is plain, that by so doing, the entrance of the ship doth make a more sudden, or is of more absolute force against the current of the water, than when in the middle of the ship, or solid, on which the experiment is tried. To account for this, I am satisfied with conceiving that by moving the midship frame nearer the fore-end of the ship than in common is done, the body thereby declines so much sooner, and takes off part of the friction caused by the lateral pressure, which appears to be of more service to the velocity, than what is lost by making the fore part of the ship somewhat fuller.

To insist that the difference in velocity of these experiments, as set down to that account, is exactly neither more nor less, than what is there mentioned, may not be strictly or scrupulously true, but that it is near the truth is demonstration; and it hath been long ago shewn by Sir *Isaac Newton*, that a blunt headed figure, impelled in the direction of its axis, was the shape of least resistance in a fluid; but the properest proportion between the length and breadth is not deduced.

In the next place it resembles nature, in the form of the fast swimming fishes, and hath been experienced with success; from all which it is become to me a rule, or pattern, that, so far as other considerations will admit, the lines that form the bodies of ships should be similar to the pattern that had the greatest velocity.

Suppose a cruising ship had all the perfections in her dimensions, and every other part, and the midship or broad-side frame placed near the middle of the ship, and built sharp at the ends; consider the weight of the fore-mast, rigging, and sails, belonging to her; the anchors at the bows, which, with the pressure of the wind into the sails, all unsupported but from the body farther aft, and united to press down into the hollow of every sea; I say, for want of more body further forward, such a ship, must plunge deep, and hinder the velocity; this is not the case of the hinder part of the ship. Another consideration is, the side resistance of the bottom of the ship must not be equally forward to that abaft, for, if it was, the ship must be trimmed greatly by the stern, or her rudder would not command her, to bear up in a gale of wind. When a ship is prest with sail, the water is forced up at the bow, a little above a level, and the ship is pressed a little down, which amounts to the same, with respect to her helm, as if the ship was trimmed by the head. Then ships that carry their tiller near the middle in light winds, require it more a weather, when it blows. Suppose, by moving the midship frame a little farther forward than M. *Duhamel* proposes, and is commonly done,

if

if it did not add to the velocity, by fo doing, provided it retard not the motion, it is of fervice for the reafons mentioned.——So far thefe Experiments.

We may now venture to affert, that by carrying the midfhip frame forward, as in the preceding experiments, we fhall gain, not only in point of velocity, but likewife, according to M. *Bouguer's* own principle, in point of fteerage, which will be a double advantage.

As thefe experiments were made in ftill water, it may be prefumed, when a fhip is to encounter a great head fea, there will be at leaft as much, if not more occafion for a full bow.

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The Method of bevelling the Cant Timbers by the Diagonal Ribbands, and likewise the Fashion Piece of a Square-Tuck, by Water Lines.

* To bevel the Cant Timbers by Ribbands.

THE angle F o b, (*Plate* VII. in the foregoing treatise) will be the angle which the fashion piece will make with the third ribband : For o being the point where the plane of the fashion piece interfects the third ribband ; a line drawn from o to F, will be the line in which the plane of the timber interfects the plane of the ribband : But then, as thefe planes are not perpendicular to one another, the angle F o b will not be the true bevelling, unlefs the bevel be fo applied that the tongue may be in the direction of the ribband, and then the ftock cannot lay flat upon the fide of the timber :: For which reafon this method will not do for practice ; for the fureft way to take any bevelling, is when both the ftock and the tongue of the bevel are fquare to the timber.

In order then to find the true bevelling upon a fquare, the direction in which the ribband interfects the timber muft be given, as well as the angle F o b ; and likewife the breadth of the timber : Now if thefe three be given, the angle upon the fquare may with certainty be found by the follow method.

Let the diftance betwixt the parallel lines A B and E F be the breadth of the timber ; B a the direction of the ribband ; and a b what the bevelling is without a fquare. (*See the* Fig. *under the* Scale, Plate VII.)

Now, that we may the eafier conceive how this bevelling may be found, let us fuppofe the timber to be quite ftrait, fuppofe the partition of the cheft, *Page* 124 ; and firft trimmed fquare. Then, becaufe a b is what it is without a fquare, it is plain there muft be fo much lined off the aft fide of the timber ; the line a B will be the breadth of the outfide of the timber, in that direction before the wood is taken off ; and if B D be made equal to B a, and D d equal to a b, and the angle at D a right one ; then it is plain the angle A B d, equal to the angle F o b, will be the bevelling, if the tongue of the bevel can be kept in the direction of the line B a : But when the ftock of the bevel is laid flat on the fide of

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* Thefe directions are again inferted in the *Supplement* for the benefit of the Purchafers of the firft Edition.

the

the timber, the tongue will naturally be perpendicular to the plane of the timber, which will be in the line B F; and if F *f* be made equal and parallel to D *d*; then will the angle A B *f*, be the true bevelling upon a fquare.

DEMONSTRATION. (*Plate* VII.)

In the right angled triangle *a* F B, B F the breadth of the timber is given, and *a* B the common fection of the plane of the ribband, with the plane of the timber; again in the right angled triangle *b a* B or B D *d*, its equal, we have *a* B or B D the breadth of the timber in the direction of the ribband, when the timber is yet fquare, and *b a*, or D *d*, what the bevelling is without a fquare, fo the angle A B D will be the bevelling.

But if B F were the common fection of the ribband, and timber, then the line of direction would be fquare to the timber, which does not alter what the bevelling is without a fquare, *viz.* the line *a* B or D *d*.

In the right angled triangle F B *f*, F *f*, and F B are given, hence we have the angle A B *f*, the bevelling on a fquare; but it is plain the ribband will be higher on the aft than on the fore fide, when in the after body, and the contrary when in the fore body; therefore the heighth of the ribband muft be transferred from the contra to the moulding fide, which muft be the firmark when the bevel is fquare to the timber; fo the firft thing to be done, is to find the height of the ribband, on the contra fide, for its heighth on the moulding fide is given before the timber can be formed.

Before we give direction how to find this, it will be proper to obferve, firft, that tho' the planes of the fquare timbers interfect the planes of the ribbands in the diagonals, in the body plane, yet the cant-timbers do not, for the plane of the 4th ribband cuts the plane of the fafhion piece, in the line *r* F, and not in the line *r s*. Secondly, we muft remark, that the breadth of the timber muft be determined, which, fuppofe F *e* in the floor plane, fo fhall *r* B reprefent the forefide of the fafhion piece, on the floor plane, it being parallel to F P, which reprefents the aft fide: Let F *e* be fquare to the point F; fo the fore fide of the plane of the fafhion piece muft be broader than the aft fide, by the length of the line B *e*, that being what its bevelling to the fheer plane is without a fquare; this being premifed, we may find the heighth of the third ribband, on the contra fide of the fafhion piece, and from thence find the bevelling of the cant timber by the following method :

1ft.

1*st*. Take B *e*, that is, what the fore fide of the plane of the fafhion piece is without a fquare ; fet this off on the perpendicular *r d*, in the body plane, and draw the line *d d* parallel to K O.

Note. The line *d d* will be in the fore body for the after cant timbers, and in the after body for the fore cant timbers.

2*d*. Produce the common fections of the planes of the ribbands, on the aft fide of the fafhion piece, to cut the line *d d*, as F *r* in the plate meets the line *d d* in *e*.

3*d*. From the point *d* draw a line parallel to *r* F, which will be the common fection of the plane of the ribband and the plane of the forefide of the fafhion piece ; ufe the fame operations for finding the other ribbands, as you fee in the plate, and call them new diagonals.

4*th*. Find points in thefe new diagonals thro' which the curve of another cant timber would pafs, this will be the fore fide of the fafhion piece, obferving that the lines taken from the floor plane muft be fet off from the line *d d*, and not from the line K O ; the diftance of thefe points from the curve of the aft fide of the fafhion piece will be what the bevellings is, within or without the fquare. In applying the bevel, the ftock muft be laid on the new diagonals, but when this is not fquare to the timber, take the neareft diftance to the curve of the moulded fide of the timber from the forefaid points, and there place the firmark, fo the ftock and tongue will be fquare to the timber, as in the firft ribband, and from thefe points make an exact bevelling board, as in the plate ; the like procefs may be ufed for the fore body.

The difference of the heighth of the ribbands on the moulding, and contra fide, may be had by projecting the planes of the diagonal ribbands on the fheer plane. The forms and bevellings of all the other cant timbers may be had by the fame method, but every timber will require another line, for the line *d d* will fall betwixt that and the line K O, till at laft it coincides with it, that is, when the timber has no cant, and the new diagonals will be approaching to thofe that reprefent the planes of the fquare timbers in the body plane.

The cant timbers may likewife be bevelled by water lines ; their planes are reprefented by level lines in the body plane, which, in fome cafes, will be very oblique to the curve of the timbers, but this may be reduced to a fquare, and the bevellings found as before directed : See that of the firft tranfom in the plate.

To bevel the fafhion piece of a fquare tuck by water lines.

The fafhion piece of a fquare tuck may bevelled by water lines, in the fame manner the cant timbers are by ribbands, for as it both rakes and

cants,

cants, the planes of the water lines will interfect it higher on the aft than on the foreside; and, before we have their heights on the foreside, the breadth of the timber muft be determined, which fuppofe *b n* (*Fig.* 71.); but this is not all, for, as it cants, the breadth in the direction of the water line, will be more than the true breadth: In order to find the true breadth, form the aft fide of the fashion piece, as directed in page 140; but, as we intend here to allow for the thicknefs of the plank, we fhall alter both the rake and cant.

Let *t* 5 (*Fig.* 69.) be the aft fide of the rabbit on the out fide of the poft; W M the common fection of the plane of the fashion piece, and fheer plane; but before this laft line can be determined, draw the feveral water lines 1, 2, 3, 4, and 5, parallel to the keel, which may reprefent fo many tranfoms; let all thefe water lines be formed and ended at the aft fide of the rabbit, as in *Fig.* 70, where the round aft of the tranfoms is defcribed, and limits the curves of the water lines. Now the line W M muft rake fo as to leave room for half the thicknefs of the poft at the tuck; in order to which, produce W *g* to *r*, make *r g* half the thicknefs of the poft, thro'. *r* draw a line parallel to *g* M, to interfect *g* G in *b*; with the radius *r b* from *x*, the point of the tuck as center, defcribe an arch, and draw the line W M juft to touch the back of that arch.

The lines parallel to *g* G muft likewife be fo drawn as to cut off no part of the tranfoms in (*Fig.* 70.) the lines *g* G, *a* 4, *s* 3, are abaft the ends of the tranfoms, fo all that wood muft be taken off after the fashion piece is bevelled.

Having thus drawn the line W M, firft affume any point *k*, at pleafure; in the line W M, *Fig.* 69, let fall the perpendicular *k y*, and draw *y f* parallel to *g* G, to interfect a perpendicular drawn from the point M in *f*, *Fig.* 70.

2*d.* From M draw the line M 1 fquare to *y f*, and then the line *y n* fquare to W M.

3*d.* Make M *n*, *Fig.* 71, (equal to M 1, *Fig.* 70.) the bafe of the right angled triangle *k n* M, of which M *k* is the perpendicular equal to *k y*; fo the angle *k n* M will be the bevelling to the horizontal plane; and to find its bevelling to the fheer plane.

1*ft.* Make M *z*, *Fig.* 71. (equal to *n y*, *Fig.* 70.) the bafe of the right angled triangle *f z* M, *Fig.* 71, of which, *f* M the perpendicular, is equal to *f* M, *Fig.* 70; fo the angle *f z* M will be the bevelling to the fheer, as demonftrated in page 126.

Having thus found the bevellings, draw the line *a b*, *Fig.* 71, parallel to *z n*; let *z a*, equal *n b*, be the fcantling of the timber, then *n x* will be the

the breadth of timber on the horizontal, and *z c* its breadth on the sheer plane, and *a c* what it is within a square.

Now, as the lines *g* G, *a* 4, *s* 3, *b* 2, *y* 1, reprefent the aft side of the fashion piece on the horizontal plane, *Fig.* 70, we may draw the dotted lines parallel to them to reprefent the fore side as in the plate; making *n x*, *Fig.* 71, the fquare diftance betwixt them, and their correfpondings on the aft side, and by these dotted lines form the forefide of the fashion piece in the same manner the aft side was formed; but the water lines on the fore side of the plane of the fashion piece muft firft be drawn, in *Fig.* 69. Thus,

1ft. Draw the lines *e b* and *c d* parallel to W M, (*Fig.* 69.) making the diftance betwixt W M and *e b* equal to *a c*, (*Fig.* 71.) and the diftance betwixt W M and *c d* equal to *z c*. (*Fig.* 71.)

2d. Draw a line parallel to W F, through the point where the line *c d* interfects the fifth water line, *Fig.* 69; draw a line parallel to *a* A, through the point where the fourth water-line interfects the line *c d*. Do the same by all the water-lines.

We may now project the fore-side of the fashion-piece by the new water-lines, obferving that the diftances muft be set off from the line *e b*, and not from the line W M; or find the points through which the curve should pafs on these new water-lines, and the neareft diftance betwixt these points and the curve of the aft side, is what the bevelling is without a fquare, when both ftock and tongue are fquare to the timber; and, when the water-lines are not fquare to the timber, reduce the bevelling to a fquare one, and place the firmarks on the moulding edge, as you fee in the plate, and from thence transfer the bevellings to a board, the exact breadth of the timber.

After the timber is trimmed and bevelled from the aft side, there will be a fpiling, *e d*, (*Fig.* 70.) to be set off forward from the line G *g* produced; and a fpiling, *c o*, from *a* 4 produced; laftly, a fpiling, *l m*, from *s* 3 produced; and as the aft side of the fashion-piece winds, there muft likewife be fpilings set off for the infide, as in *Fig.* 69.

Let 11, 12, 13, 14, *Fig.* 69, be the infide of the fashion-piece; make *g*, 11, *Fig.* 70, equal to W, 11, *Fig.* 69; *a*, 12, *Fig.* 70, equal to *a*, 12, *Fig.* 69, &c. So 11, 12, 13, 14, will be the fpilings, and wear off at the point 1; *Fig.* 70.

There will be no occafion to fide the moulding fide of the fashion-piece quite ftrait; it may be fided fo, that, when the mould is flightly faftened to it, the head of the fashion-piece may round from the mould nearly the whole quantity of the fpiling, and then it may be bevelled from the mould, and afterwards the proper fpilings set off.

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The timber being thus trimmed, the planks will come to the aft side of the fashion-piece, which will make the ends apt to start off with the caulking; to prevent which the thickness of the plank must be set off without the moulding edge of the fashion-piece, as in the plate; and, when the fashion-piece is bevelled to this mould, we shall have the whole thickness of the plank, without the moulding edge both of the aft and fore sides; so the planks may be rabbitted into the fashion-piece, leaving substance enough on the aft side to cover the ends of the planks. The planes of the timbers, in some cases, cut the plank very obliquely, which will occasion the plank to be thicker in that direction than really it is; therefore the thickness of the plank, in the direction of the plane of the timber, at each water-line, must be determined before the mould can be made. This will be a very difficult task; however, we shall endeavour to perform it in the following manner.

1ft. Draw a line square to the second water-line, at the point 2, where the plane of the fashion-piece intersects it on the floor plane, *Fig.* 70; and produce this line, from the middle line, to intersect all the other water-lines, which must be produced for that purpose; so the square line, in *Fig.* 70, will be 2, 2, *v*.

2d. Form a cant timber in the direction, or cant of that line, as in *Fig.* 68.

3d. Set off the real thickness of the plank square from this timber, to intersect the corresponding water-line in the point *r*; so *r s* will be the thickness of the plank on the plane of the water-line.

4th. Set off *r s* parallel to the second water-line, *Fig.* 70; to avoid confusion this was done by a pencil, and we have only the point *t* in the plate, where the plane of the fashion-piece intersects it.

5th. Produce *b* 2, *Fig.* 70, to intersect the curve in *t*; so *t* 2 will be the thickness of the plank in the direction of that line.

6th. Produce the line *b* H, *Fig.* 69, to *q*, making *b q*, *Fig.* 69, equal to *b t*, *Fig.* 70; so *q* will be one point of the curve.

Though this method may be too tedious for practice, yet, as it seems to bear a mathematical demonstration, we have adventured to insert it; far from imagining that there are not other methods better adapted for that purpose; for, without some such contrivance, a ship could not be built exactly of the same dimensions with another already built, having only the dimensions of this last, by taking them off when in a dock, which must be from the outside of the plank; whereas, when they form the timbers, the dimensions must be taken from the inside of the plank.

Supp.   O   *On*

On the Masting of SHIPS.

AS M. *Bouguer* has given us the general proportions for the length and diameter of masts and yards used in *France*, it may be expected we should give the proportions used in *England*.

It must be owned, the art of masting ships is quite as imperfect as that of forming the bodies, for they bear no manner of proportion to any of the other dimensions of the ships, and seem to be wholly regulated by the judgment and experience of the commanders. This will appear very plain by examining the dimensions of the masts and yards of the following ships, and comparing them with the breadths and lengths of those ships, and yet their commanders were all allowed to be expert seamen.

Dimensions of Masts for EAST-INDIA Ships.

	Length. Feet.	Diameter. Inches.		Length. Feet.	Diameter. Inches.
MAIN-MAST	80	24½	MAIN-YARD	66	16½
Top-mast	50	15	Do.	52	12⅔
Top-gallant-mast	28	8	Do.	36	6
FORE-MAST	72	24	Do.	60	15
Top-mast	48	15	Do.	48	12
Top-gallant-mast	25	7½	Do.	34	5¾
MIZEN-MAST	70	17	Do.	61	12½
Top-mast	36	10	Do.	36	7¾
Bowsprit	50	25	Do.	50	12
Jyb-boom	36	11	Crofsjack	50	11¼

Dimensions of Capt. KENNEDY's Masts and Yards, of about 182 Tuns.

	Length. Feet.	Diam. Inch.		Length. Feet.
MAIN-MAST	62	16½	YARD	44
Top-mast	33	10	Do.	32
Top-gallant-mast	18	5½	Do.	24
FORE-MAST	56	16½	Do.	39
Top mast	30	9½	Do.	39
Top-gallant-mast	16	5	Do.	22
MIZEN-MAST	53	11	Do.	40
Top-mast	28	6½	Do.	24
Bowsprit	36	16½	Crofsjack and fpritfail 32 feet long;	
Extreme breadth	23		Spritfail topsail-yard 24	

Length on the lower deck from the aft side of the stem to the fore } f. in. side of the stern-post { 81 8

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Dimenſions of Captain ALLEN's Maſts and Yards, about 176 Tuns.

	Maſts.		Yards.
	Length. Feet.	Diam. Inches.	Len. Feet.
MAIN-MAST	63	16¼	44
Do. top	33	10½	33
Do. top-gallant			25
FORE-MAST	58	16	39
Do. top	31	10½	33
Do. top-gall.			23
MIZEN-MAST	53	11½	h.miz.
Do. top			25
Bowſprit	37	16	31
Croſsjack			32

Breadth 23 f. 2 in.
Length low. deck 78 feet, 11½ in.

Capt. LYONS, about 167 Tuns.

	Maſts.		Yards.
	Length. Feet.	Diam. Inch.	Len. Feet.
MAIN-MAST	60	16¼	42
Do. top	33	10	32
Do. top gall.	18	5¼	24
FORE-MAST	54	16	37
Do. top	30	9½	30
Do. top-gall.	16	5	22
MIZEN-MAST	52	11	40
Do. top	28	6½	24
Bowſprit	36	16½	32
Croſsjack			32

Breadth 22 feet, 6 inches.
Length low. deck 79 feet, 1 inch.

Capt. BOWMAN, about 162 Tuns.

	Maſts.		Yards.
	Length. Feet.	Diam. Inches.	Len. Feet.
MAIN-MAST	60	16	41
Do. top	32	10	31
Do. top-gall.	17	5	24
FORE-MAST	54	15½	36
Do. top	28½	9½	28
Do. top-gall.	15	4½	22
MIZEN-MAST	50	11	20
Do. top.	25	6	25
Bowſprit	34½	16½	30
Croſsjack			30

Extreme breadth 22 feet, 6 inches
Length lower deck 76 feet, 6 inches

Capt. DERRY's, about 150 Tuns.

	Maſts.		Yards.
	Length. Feet.	Diam. Inches.	Len. Feet.
MAIN-MAST	58	16	40
Do. top	31	9½	30
Do. top-gall.	18	5¼	23
FORE-MAST	52	15½	36
Do. top	29	9½	28
Do. top-gall.	15	5¼	21
MIZEN-MAST	49	11	37
Do. top	27	7	23
Bowſprit	35	16	30
Gibb boom,		7	27

Extreme breadth 22 feet.
Length l. deck 74 feet, 4 inches.

Capt.

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Capt. HILL, 130 Tun.

	Masts.			Yards.
	Lengths. Feet.	Heads. f. in.	Diam. Inch.	Len. Feet.
MAIN-MAST	55	7 6	14¾	39
Do. top	29	3 3	9	30
Do. top-gall.	18	3 0	4¾	23
FORE-MAST	50	7 0	13¾	35
Do. top	27	3 0	8½	29
Do. top-gal.	16	2 0	4½	21
MIZEN-MAST	46	5 0	10	22
Do. top	21	3 0	6	24
Bowsprit	35		14½	29

Extreme breadth 21 f. 2½ in.
Length lower deck 67 4.

Capt. HOULDERSON, Billander, about 160 Tuns.

	Masts.		Yards.
	Length. Feet.	Diam. Inch.	Len. Feet.
MAIN-MAST	68	16½	40
Do. top	68	10	29
FORE-MAST	54	15	38
Do. top	30	9	29
Do. top-gallant	18	5	23
Bowsprit	36	15	
Gibb boom			26

Breadth 21 feet.
Lower deck length 71 f. 4 in.

Capt. ———, 131 Tuns.

	Masts.		Yards.
	Len. Feet.	Diam. Inches.	Len. Feet.
MAIN-MAST	57	16	40
Do. top	30	9½	30
Do. top-gallant	18	5	28
FORE-MAST	52	15½	35
Do. top	28	9½	28
Do. top-gallant	15	4¾	21
MIZEN-MAST	50	10½	22
Do. top	26	6½	23
Bowsprit	34	16	30
	Crofsjack.		30

Breadth 21 feet, 2 inches.
Lower deck length 73 f. 3 in.

Capt. ROBIN'S, Snow, 130 Tuns.

	Masts.		Yards.
	Len. Feet.	Diam. Inches.	Len. Feet.
MAIN-MAST	56	15	40
Do. top	30	9	30
Do. top-gallant	17		24
FORE-MAST	50	14¼	36
Do. top	28	9	28
Do. top-gallant	15		22
Bowsprit	35	15	30

Breadth 21 feet.
Lower deck len. 71 feet, 4 inches.

N. B. The three lower masts were shortened two feet each, and the yards ten inches at each end.

Capt.

Capt. SMITH's Sloop, 100 Tuns.	Length Feet.	Diam. In.
Maſt	80	19
Bowſprit	44	15
Boom	52	12¼
Gaph	28	
Spread-yard	40	
Topſail-yard	33	
Croſsjack	36	
Top-gallant-maſt	19	
Do. yard	28	
Gibb boom	30	
Breadth	20	
Length	61	

Capt. GILBER's Sloop, 83 Tuns.	Length Feet.	Diam. In.
Maſt	73	17
Bowſprit	42	14
Boom		50
Spread-yard	37	
Top-ſail-yard	26	
Croſsjack	33	
Top-gallant-maſt	13	
Do. yard	22	
Gibb boom	26	
Breadth	18 f. 9 in	
Length	57 f. 2 in	

Capt. NICKALL's Sloop, 52 Tuns.	Length Feet.	Diam. In.
Maſt	65	15
Top-maſt	14	
Top-gallant-maſt	21	5
Bowſprit	40	11
Boom	44	
Gaph	24	
Spread-yard	34	
Topſail, Do.	27	
Top-gallant, Do.	26	
Croſsjack, Do.	30	
Breadth	16	

Proportions for Maſts and Yards in the Royal Navy.

THE maſts are proportioned to the extreme breadth of the ſhip from out to out, and the yards to the length of the gun deck; and as this treatiſe is chiefly deſigned for the ſhip-wrights of his Majeſty's dock yards, we ſhall here give the general proportions of maſts and yards, for the benefit of ſuch of them as may be employed at ſea.

As to the form of maſts and yards, the general method is to quarter the maſts from the partners to the hounds, and the yards from the ſlings to the yard arms; ſo that both yard arms are exactly the ſame, except the mizen yard. The diameters at the quarters are in proportion to that at the partners or ſlings; whether this curve will be an arch of a circle or of an ellipſe, or only a fair curve, we ſhall not at preſent examine, only give our readers the proportions; but as the beams are allowed to be arches of circles, we ſhall here ſhew a ready way of making a beam mould.

Let A B, Fig. 73, be the length of the beam, C D the round in the middle, ſo it is only deſcribing a circle thro' the three points A D B; but as the circle in ſome caſes will be ſo large that we cannot come at the center we may uſe the following method.

1ſt. Draw the lines A D and D B.

2d. From

2*d.* From the center D, and with the radius D C, deſcribe a circle; make the arch *a e* equal to the arch C *a*, and the arch *b f* equal to the arch C *b*, ſo the arches *a e*, and *b f*, will be equal, and of conſequence, the angles A D C, A D *e*, B D C, B D *f*, will all be equal.

3*d.* Divide the lines D C, D *e*, and D *f* into as many equal parts as you propoſe to find points in the curve; it is indifferent whether theſe parts be equal or unequal; only obſerving to begin the diviſions from the point D, and that the diviſions of the lines D *e*, and D *f*, be the ſame diſtance from the point D that their correſponding diviſions in the line D C are from the ſame point.

4*th.* Draw the line B *x* to the firſt diviſion of the line D *f*, and a line from A, thro' *z* (the firſt diviſion of the line D C), to interſect the line B *x* in *g*, which will be one point in the curve.

In like manner the other points are found, by drawing lines from B to the ſeveral diviſions of the line D *f*, and lines from A thro' the correſponding diviſions of the line D C, to interſect thoſe drawn from B, which will all be in the circumference of the circle. In the figure we have only drawn the lines B *x*, and A *g*; but, in practice, we may take two chalk lines and faſten one at A and the other at B, and ſtretching the one thro' the points in the line D C, and the other thro' the correſponding points in the lines D *f*, and D *e*, the interſections of the chalk lines will give the ſeveral points in the circumference.

DEMONSTRATION.

The angle at the circumference of a circle is meaſured by half the oppoſite arch, as demonſtrated in page 28. Hence all angles at the circumference of a circle that ſtand on the ſame chord are equal, and of conſequence, if there be never ſo many equal angles ſtanding on the ſame chord, they will be all in the circumference of a circle; or, which is the ſame thing, a curve drawn thro' the ſeveral angular points will be an arch of a circle.

The triangles B D *x*, and A D *z* are equal, for the ſides A D, and D B are equal, the ſides D *x*, and D *z* are likewiſe equal, and the angle B D *x* included by the ſides B D and D *x*, equal to the angle A D *z*, included by the ſides A D and D *z*; therefore the angle D B *x* is equal to the angle D A *z*.

The angles D A B, and D B A, are equal, and ſubtracting their ſum from 180 we have the angle A D B; but the ſum of the angles *x* B A, and *z* A B, is equal to the ſum of the angles D A B, and D B A, for the angle D B *x* is added to the angle D B A, and the angle D A *z* (equal

to

to the angle D B *x*) is subtracted from the angle D A B ; therefore, the angle A *b* B is equal to the angle A D B, and of consequence the arch of the circle will pass thro' both ; the like may be said of all the rest.

Proportions for the length of Masts, Anno 1745.

			Guns
1000 : breadth in feet ::	748 :	main mast in yards	100
	756 :		90
	753 :		80
	741 :		70 and 60
	740 :		50
	747 :		44
	760 :		24
1000 : main mast ::	895 :	fore-mast	100 90 80
	901 :		all the rest
1000 : main mast ::	870 :	mizen-mast	100 90 80
	866 :		all the rest.
1000 : main mast ::	640 :	bow-sprit	100 90 80
	613 :		all the rest
1000 : main mast ::	600 :	main-top-mast	100 90 80
	605 :		70 60 50 40
	607 :		24
1000 : main-top-mast ::	900 :	fore-top-mast	100 90 80
	910 :		all the rest.
1000 : main-top-mast ::	710 :	mizen-top-mast	100 90 80
	717 :		all the rest.
1000 : main-top-mast ::	480 :	main-top gallant mast	100 90 80
	508 :		all the rest.
1000 : fore top-mast ::	480 :	fore top-gallant-mast	100 90 80
	505 :		all the rest.
1000 : bow-sprit ::	360	sprit-sail top-mast	100 90 80

Proportions for the length of yards.

			Guns
1000 : gun deck ::	560 :	main yard	100
	559 :		90 80
	570 :		70
	576 :		60
	575 :		50 24
	561 :		44
1000 : main yard ::	880 :	fore yard	100 90 80
	874 :		all the rest.

1000

1000 : main yard :: { 820 : / 847 : / 840 : } mizen yard { 100 98 80 60 44 / 70 / 24 }

1000 : main yard :: { 726 : / 720 : } main top fail yard { 24 / all the reft, }

1000 : fore yard :: { 719 : / 726 : / 715 : } fore top-fail-yard { 70 / 24 / all the reft. }

1000 : main top fail ya. :: 690 : main top gall. yard — all the rates

1000 : fore top-fail ya. :: { 696 : / 690 : } fore top gal. ya. { 70 / all the reft. }

1000 : fore top-fail ya. :: { 768 : / 750 : } miz. top-fail ya. { 70 / all the reft. }

Crofs jack and fprit-fail yards equal to the fore top-fail yard.

Sprit top-fail yard equal to the fore top gallant yard.

Having now found the length of the mafts and yards; our next bufinefs is to determine their diameters at the partners and flings.

Proportions for the Diameters of Mafts and Yards.

The main and fore maft in all fhips down to 60 guns, 1 inch diameter to every yard in length.

For 50 and 40 guns, twenty-feven twenty-eights of an inch diameter, to one yard in length.

For 24 guns, twelve thirteens of an inch diameter to one yard in length.

All top mafts are nine tenths of an inch diameter to one yard in length.

The fore top-maft as big as the main top-maft.

The top gallant maft, one inch to a yard.

The mizen-maft $\frac{15}{14}$ of an inch to 1 yard in length.

The mizen top-maft five fixths of an inch to one yard in length.

The bow-fprit an inch and half to one yard.

The flying gibb-boom feven eighths of a fhip to a yard.

The main and fore yard five fevenths of an inch to a yard.

The top-fail, crofs-jack, and fprit-fail yards nine fourteenths of an inch to one yard.

The top-gallant, mizen top-fail, and fprit-fail top fail yards eight thirteenths of an inch to one yard.

The

The mizen yard five ninths of an inch to one yard.

All steering sail booms and yards half an inch to one yard in length.

Proportions for the diameters, at the quarters of masts and yards, according to their diameters at the partners, or slings.

For the main and fore mast, first quarter $\frac{4\cdot2}{4\cdot3}$ parts; second quarter $\frac{1\cdot4}{4\cdot3}$ parts; third quarter $\frac{7}{8}$ parts; hounds $\frac{7}{8}$ parts; for the head $\frac{5}{7}$ parts; heel $\frac{5}{7}$ parts.

For the mizen mast, and sloops masts that head themselves, first quarter $\frac{6\cdot0}{6\cdot1}$; for the second quarter $\frac{1\cdot1}{1\cdot2}$; for the third quarter, a strait line from the second to the hounds; hounds three quarters; for the head two thirds.

For top and top gallant masts, first quarter $\frac{4\cdot0}{4\cdot1}$ parts; second quarter $\frac{1\cdot4}{1\cdot5}$ parts; third quarter $\frac{7}{8}$ parts; hounds $\frac{7}{8}$ parts; head $\frac{5}{6}$ parts.

For the bow-sprit, first quarter $\frac{3\cdot0}{3\cdot1}$ parts; second quarter $\frac{7}{8}$ parts; third quarter 3 quarters; at the cap one half; at the heel 3 quarters.

For yards in general; first quarter $\frac{2\cdot2}{2\cdot3}$ parts; second quarter nine tenths; third quarter seven tenths; yard arm two fifths.

For the lower arm of the mizen yard, first quarter $\frac{4\cdot0}{4\cdot1}$ parts; second quarter $\frac{1\cdot1}{1\cdot2}$ parts; third quarter $\frac{5}{6}$ parts; yard arm two thirds.

The upper arm of the mizen yard the same as yards in general.

As some of our readers may not be acquainted with the way of notation in these proportions, we refer them to what is said on that head in the first part, where the principles of the rule of proportion, and the construction of the line of numbers is explained, and the use of the sliding-rule illustrated by a great variety of examples in the rule of three.

Those that are but the least acquainted with the rule of three, know that there are three numbers given; and, that if the second be multiplied by the third, and that product divided by the first, the quotient will give the fourth term, which will have the same proportion to the third, that the second term has to the first.

The proportion for the main mast of a ship of 50 guns, is thus expressed; 1000 : 740 :: breadth : length, that is to say, (supposing the breadth be 41 feet,): If 1000 give 740, what will 41 give?

Now, in order to give a solution to this by the sliding-rule, draw out the slider till 1000 is right against 740, and right against 41, you'll find 30$\frac{1}{3}$, nearly, which is the length of the main-mast in yards: It is indif-

ferent whether 1000 be on the flider or on the rule; but if 1000 be on the flider, 41 the breadth muft likewife be on the flider, fo 740 and 30$\frac{1}{7}$, will be on the rule, and the contrary; or univerfally, the firft and fecond terms will be on the fame line of numbers, and the third and fourth on the other line of numbers, and it is indifferent whether 740, or the breadth, be the fecond term, but 1000 muft be the firft; and the length the fourth term; the one upon the flider and the other on the rule.

The diameter at the partners you will find in the proportions $\frac{27}{28}$ parts of an inch to every yard in length; that is to fay, if the maft were 28 yards long, the diameter at the partners would be 27 inches; and therefore by the rule of three 28 : 27 :: 30$\frac{1}{7}$: 29$\frac{1}{7}$; therefore, draw out the flider till 28 is againft 27, and right againft 30$\frac{1}{7}$ is 29$\frac{1}{7}$.

The diameters at the quarters are given in what the fhip-wrights call fractional parts of the diameter at the partners, or flings; that of the firft quarter of the main maft is $\frac{42}{43}$, that is to fay, if the diameter at the partners be 43, that at the firft quarter will be 42. Now the diameter at the partners, by the preceding operation, is 30$\frac{1}{7}$, fo we have three terms of the rule of three given, thus expreffed, 43 : 42 : 30$\frac{1}{7}$, and when the flider is drawn out till 43 is againft 42, we fhall find 29$\frac{1}{7}$ againft 30$\frac{1}{7}$, fo 29$\frac{1}{7}$ inches is the diameter at the firft quarter; hence we have this general rule; when the fractional part is given, draw out the flider till the denominator is right againft the numerator, then look for the diameter at the partners, or flings, on the fame line with the denominator; and right againft the partners, or flings, you have the diameter for that quarter, and by ufing the fame operation as for finding the firft quarters, we fhall find the fecond quarter 28$\frac{1}{4}$; the third 25$\frac{1}{4}$; the hound 20$\frac{1}{4}$; and at the head 17$\frac{1}{4}$.

Now, to find the length and diameter of the main yard; the length of the gun deck is 144 feet, the proportion for the length is 1000 : 575 :: 144, therefore, draw out the flider till 1000 is right againft 575, and right againft 144 is 83 nearly, which is the length of the main yard in feet.

The diameter at the flings is $\frac{1}{7}$ of an inch to every yard in length; 83 feet is 27$\frac{1}{7}$ yards, therefore draw out the flider till 7 is againft 5, and againft 27$\frac{2}{7}$ is 19$\frac{3}{7}$.

It is prefumed thefe examples may fuffice to explain the manner of notation in the preceding proportions, and likewife the method of working by the fliding-rule, which may be applied to all queftions in the rule of three, fuch as meafuring plank, and timber, wainfcoting, &c.

We

We shall now give our readers the proportions, for the heads, and hounds of masts, and likewise for the caps, tops, truffel-trees, and cross-trees.

Proportions for Heads and Hounds of Masts.

The head of the main and fore masts, five inches to one yard of the length of the mast.

Mizen-mast head, if it steps in the hold, $4\frac{1}{5}$ of an inch to one yard in length.

All top and top-gallant mast heads, four inches to a yard in length.

The length of the hounds, two fifths of their respective heads.

Proportions for Caps.

All caps, except the flying gibb boom, to be in breadth twice the diameter of their top-masts; and their lengths to be twice their breadth. The thickness of the main and fore caps, half the diameter of their breadths; the mizen cap three sevenths, and the top-masts two fifths of their respective breadths.

The flying gibb boom cap, to be in length five times the diameter of the boom, and in breadth twice its diameter, and, in depth, nine tenths of the breadth.

Proportions for Tops.

The breadth of the top thwartships, to be one third of the length of the top-mast; the mizen-top thwartships, by some, is nine thirtieths of the length of the mizen top-mast; all tops, before and aft, three fourths of what they are thwartships; the square hole five inches to a foot.

Proportions for Truffel-trees.

In length, to reach within three inches of the outer edge of the top.

The depth of the main and fore truffel-trees, $\frac{2}{5}$ of an inch to one foot in length; their breadth five sevenths of their depth.

The depth of the mizen truffel-trees, six sevenths of an inch to one foot in length; and their breadth eleven sixteenths of their depth.

The main and fore top-mast truffel-trees, to be in length the fifth part of the length of their top-gallant-masts; their depths $\frac{2}{5}$ of an inch to one foot in length, and their breadth $\frac{11}{15}$ of their depth.

The mizen-top-mast truffel-trees, half the length of the main-top-mast truffel-trees; their depth, one inch to a foot in length, and their breadth five sixths of their depth.

Pro-

Proportions for Cross-trees.

The length of the cross-trees, for the main and fore cross-trees, to reach within three inches of the outer edge of the top.

The mizen cross-trees, the same length with the truffel-trees.

The cross-trees the same breadth with the truffel-trees, and half their depth.

Weight of Anchors, and Dimensions of Cables.

In the merchant service, the sheet, best, and small bower anchors are generally different, but in the navy these three are of the same weight. The dimensions of the cables are estimated by their circumferences.

ANCHORS.	100 Guns.	90 Guns.	80 Guns.	74 Guns.	64 Guns.	50 Guns.	40 Guns.	32 Guns.	Sloops.
	C. qrs.	C. qrs.	C. qrs.	C. qrs.	C. qrs.	C. qrs.	C. qrs.	C. qrs.	C. qrs.
Bowers	77 0	71 2	66 2	71 2	54 2	44 0	37 3	32 0	15 0
Stream	19 2	17 0	15 2	13 1	13 0	11 0	10 2	8 1	7 0

CABLES.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.	inches.
Sheet & bow.	23	22	21	22	$18\frac{1}{2}$	$17\frac{1}{2}$	16	$14\frac{1}{2}$	13
Stream	$14\frac{1}{2}$	$13\frac{1}{2}$	13	$13\frac{1}{2}$	$11\frac{1}{2}$	11	10	$8\frac{1}{2}$	8
Hawsers	$9\frac{1}{2}$	9	$8\frac{1}{2}$	9	8	$7\frac{1}{2}$	$6\frac{1}{2}$	$5\frac{1}{2}$	$4\frac{1}{2}$
ditto	9	$8\frac{1}{2}$	8	$8\frac{1}{2}$	$7\frac{1}{2}$	$6\frac{1}{2}$	$6\frac{1}{2}$	$5\frac{1}{2}$	$4\frac{1}{2}$

A Table of the Number of Guns on each Deck, their Length, Weight of Metal, and Shot.

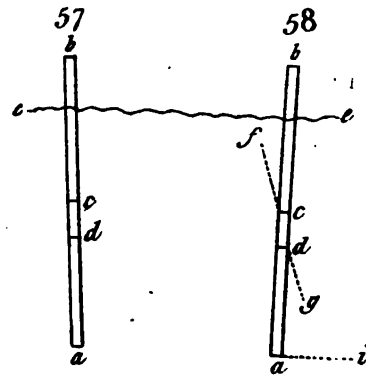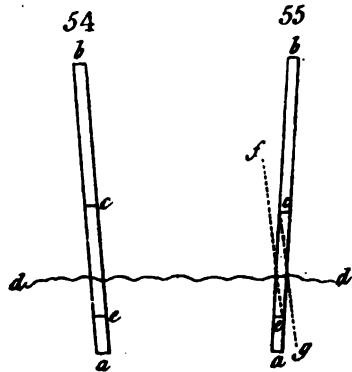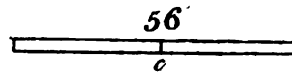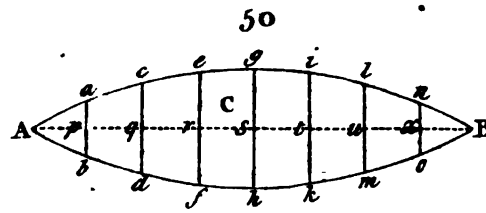| Guns	DECKS	Number on each	Length feet in.	Wt. of metal. C wt.	Wt. of shot. pounds.
	Lower	28	10 0	67	42
	Middle	28	9 6	49	24
100	Upper	28	9 6	34	12
	Quarter	12	8 0	22	6
	Fore Castle	4	9 0	24	6
	Lower	26	9 6	55	32
	Middle	26	9 6	42	18
90	Upper	26	9 0	32	12
	Quarter	10	8 0	22	6
	Fore Castle	2	9 0	24	6

A Table of the Number of Guns on each Deck, their Length, Weight of Metal, and Shot.

Guns	Decks	Number on each	Length feet in.		Wt. of metal. Cwt.	Wt. of fhot. pounds.
80	Lower	26	9	6	55	32
	Middle	26	9	0	40	18
	Upper	24	9	0	29	9
	Quarter	4	7	6	20½	6
74	Lower	28	9	6	55	32
	Upper	28	9	0	40	18
	Quarter	16	8	0	26½	9
	Fore Caftle	2	9	0	29	9
64	Lower	26	9	6	55	32
	Upper	26	9	0	40	18
	Quarter	10	7	6	24½	9
	Fore Caftle	2	8	6	27½	9
60	Lower	24	9	6	49	24
	Upper	24	9	0	32½	12
	Quarter	8	7	0	20½	6
	Fore Caftle	2	8	6	23	6
50	Lower	22	9	0	47½	24
	Upper	22	8	6	31	12
	Quarter	4	7	8	18	6
	Fore Caftle	2			22	6
44	Lower	20	9	0	40	18
	Upper	20	8	0	26	9
	Quarter	4	6	6	18	
24	Lower	2	7	0	23	9
	Upper	20	7	0	23	9
	Quarter	2	4	6	7¼	3

F I N I S.

3

5 W   2A
Z   2G
4 5   2F
8
Δ   2E
D   2B

4

D E G H W   K
Q   R S
L   4
C   B   3
M   2
N   1
O   P
A

6

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M   H
R   F
S   C
E

7

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C   D   E
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G   A
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C   D
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ℓ   A
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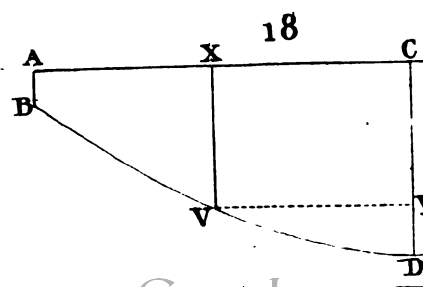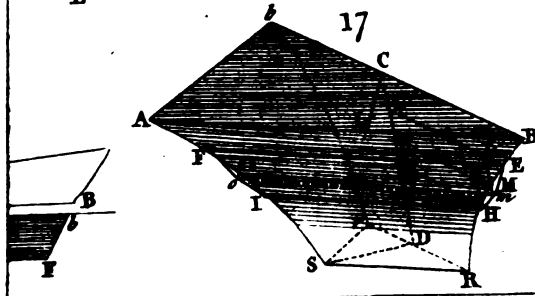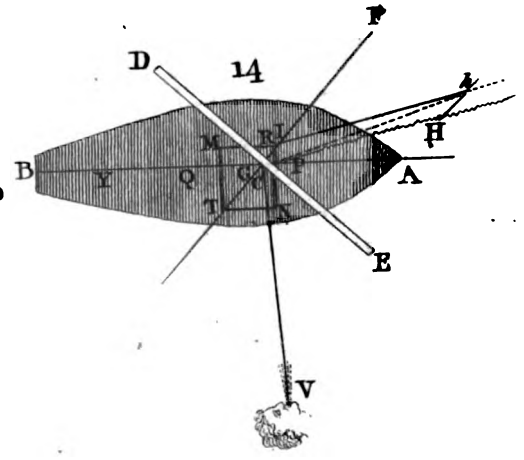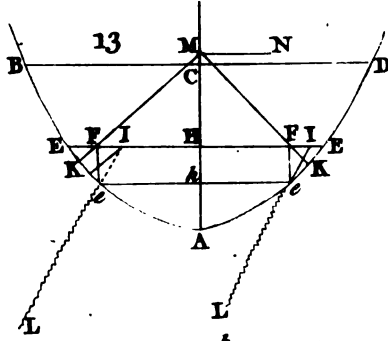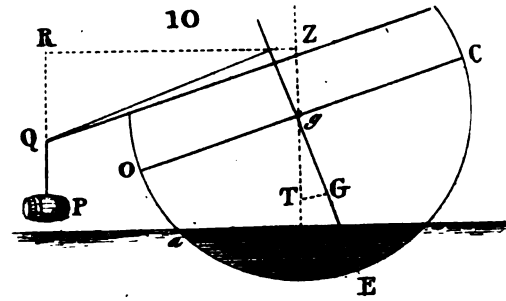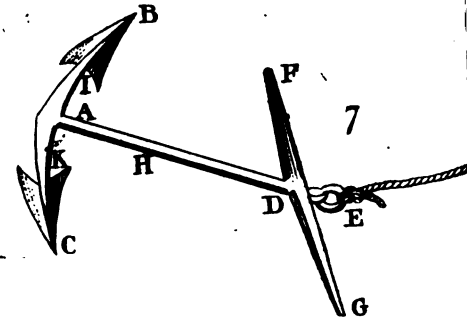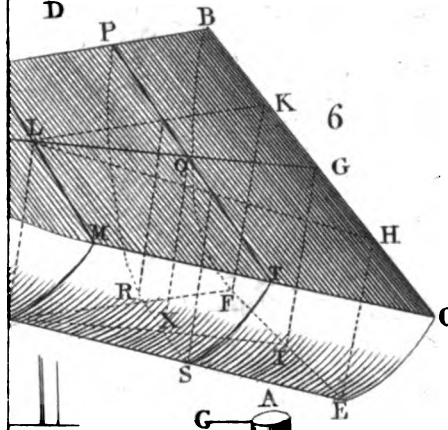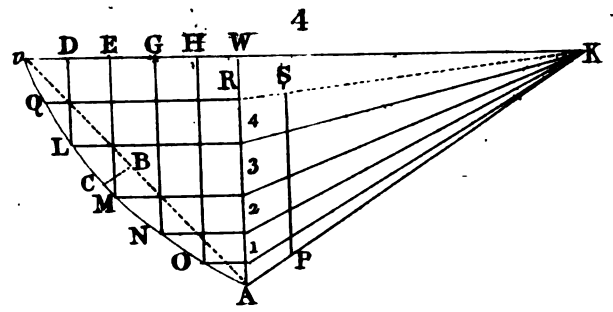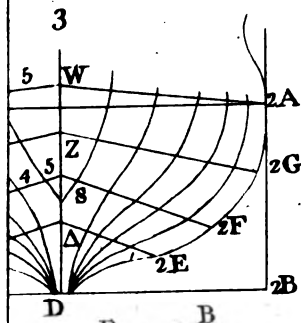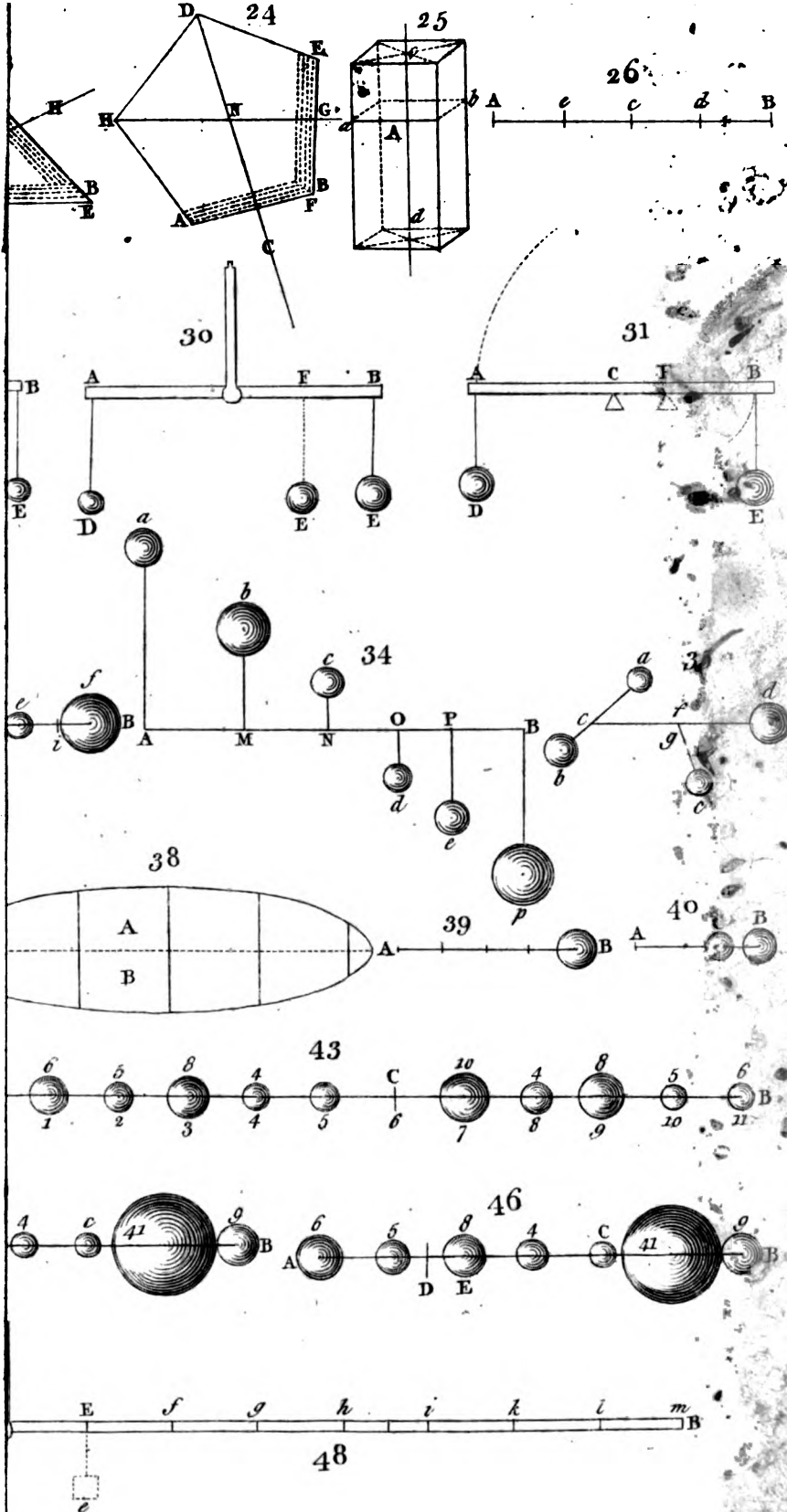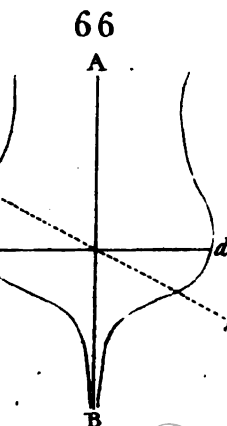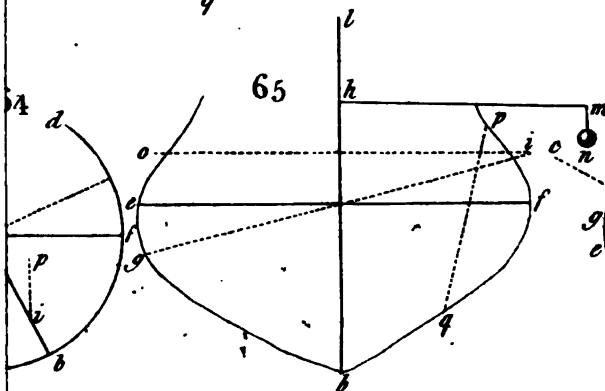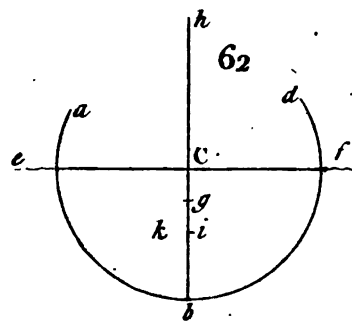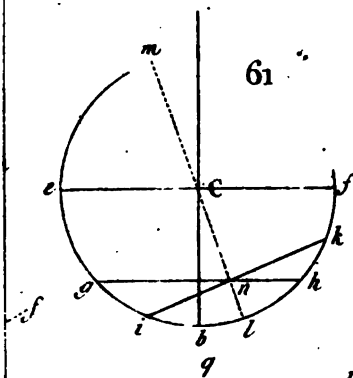
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